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GEOPHYSICS

A Journal of General and Applied Geophysics

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The Society of Exploration Geophysicists

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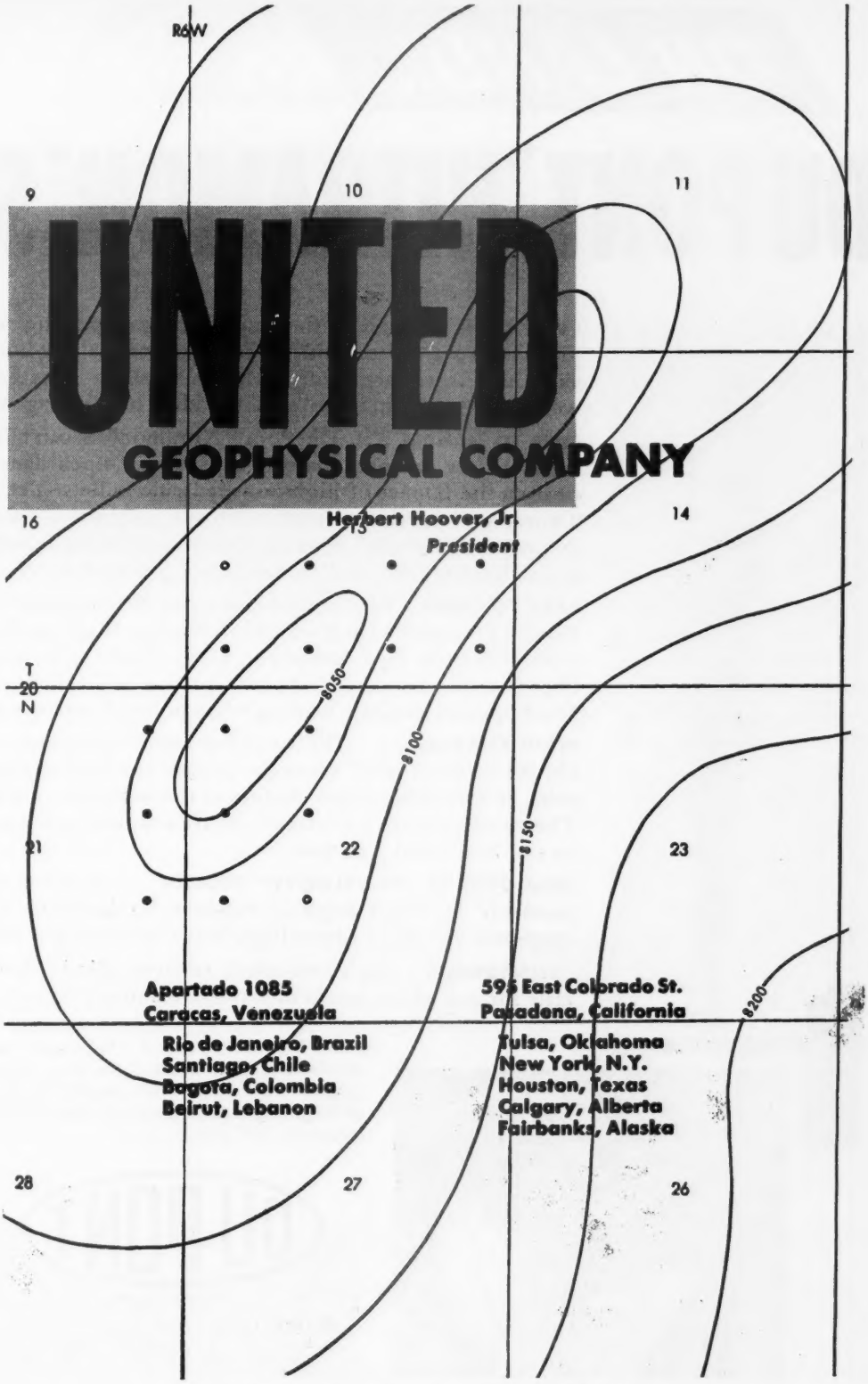

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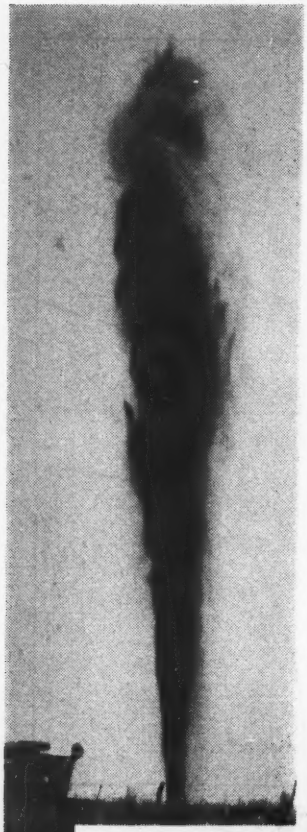

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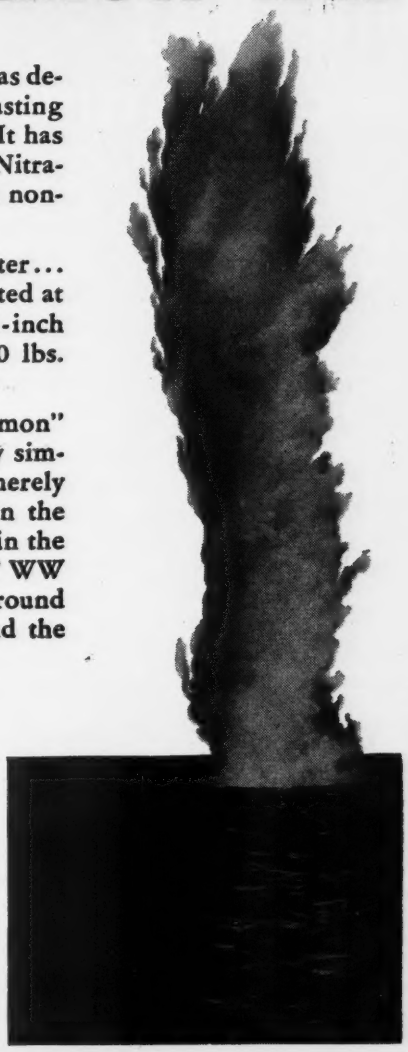

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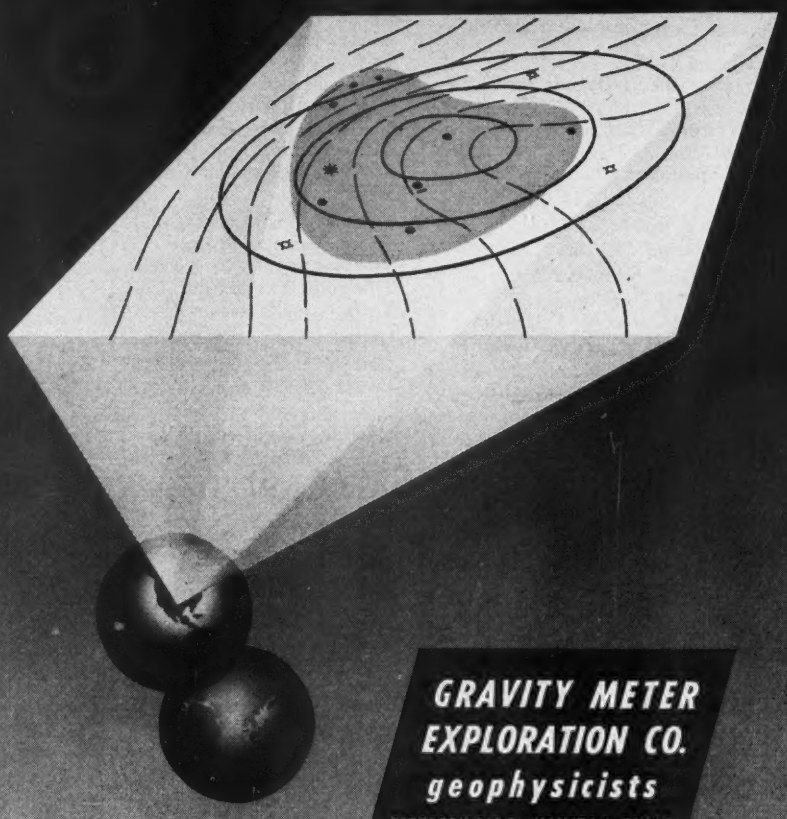

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VOLUME XIV JULY, 1949 NUMBER 3

GEOPHYSICS

A Journal of General and Applied Geophysics

GEOPHYSICS, GEOLOGY AND OIL FINDING*

L. L. NETTLETON†

ABSTRACT

As geophysics has matured in recent years, its important place as a tool in oil exploration has been generally recognized. The operation of the partnership between geologist and geophysicist is relatively straightforward in reflection seismograph exploration as the geophysical maps are similar to those with which geologists are familiar. In geophysical methods based on potential fields (gravity and magnetic) the relations to geology are not so direct and the possible ambiguities are much greater. Close cooperation of geophysicist and geologist in the evaluation of such surveys should produce particularly fruitful results. Some specific examples of both regional and local nature are illustrated and discussed.

The mutual interests of geologists and geophysicists in the broad operations of oil exploration have been generally recognized. The boundary between the proper province of the two sciences is nebulous and varies with circumstances and particular problems. If we may take the presidential addresses from this platform as a measure, the interest in the partnership between geologists and geophysicists has been much more actively expressed by the S.E.G. than by the A.A.P.G.

In the past ten years, none of the A.A.P.G. Presidents have had this subject as a principal interest, but it has been considered by several of those of the S.E.G. In 1940 Eckhardt[1] outlined the partnership between geology and geophysics in prospecting for oil; Wyckoff[2] in 1944 pointed out the place of the geophysicist in exploration decisions; Cortes[3] in 1946 initiated the publication of geophysical case histories which is now an accomplished fact in a book that should be extremely useful to both geologists and geophysicists; Green[4] last year

* Address of Retiring President, Society of Exploration Geophysicists, joint meeting A.A.P.G., S.E.P.M. and S.E.G., St. Louis, Missouri, March 15, 1949. Manuscript received by the Editor May 9, 1949.

† Gravity Meter Exploration Company, Houston, Texas.

[1] E. A. Eckhardt; "Partnership between Geology and Geophysics in Prospecting for Oil"; *Geophysics*, 3, I, (July 1940) 209.

[2] R. D. Wyckoff; "Geophysics Looks Forward;" *Geophysics, IX*, 3 (July 1944) 287.

[3] Henry C. Cortes; "Publication of Geophysical Case Histories," *Geophysics XI*, 3 (July 1946) 287.

[4] Cecil H. Green; "Integration in Exploration," *Geophysics XIII*, 3 (July 1948) 365.

discussed integration in exploration and showed how the different geological and geophysical facts can be brought to bear together on the exploration problem. The remarks of this paper are a continuation of the theme of geological-geophysical cooperation, and will include some specific cases where joint consideration of the problems is necessary for a solution.

In reflection seismograph exploration in favorable areas, the resulting maps obtained directly from strictly physical measurements can be turned over to a geologist as an accurate representation of one or more subsurface horizons. In this case the boundary between geophysics and geology is quite distinct and the geologist can take the facts presented by the geophysicist and fit them into his own data and concepts of an area. To those geologists who would use geophysics as a handy tool for their work, this is an ideal situation.

In less favorable areas, as seismograph results become more complicated or less definite, an increasing amount of geological training on the part of the geophysicist, or consultation with geologists becomes necessary before a geophysical map is ready to be made a part of the usable subsurface data of an area.

There is a fundamental difference when we consider geophysical exploration based on potential fields, which, for oil exploration include gravity and magnetic methods. The strictly physical part of the observations and the resulting maps, even in ideal circumstances and when carried out to any degree of precision and adequacy desired, can not give a geological picture directly. This results from the fundamental fact that there is no single distribution of mass or of magnetic material which will produce a given gravity or magnetic pattern, no matter how completely that pattern may be determined.

From physical measurements the geophysicist can calculate certain limits on the anomalies of mass or of magnetization which can produce the observed picture. He can say that the anomaly cannot come from greater than a certain depth; it could come from various levels or combinations of levels between the surface and that depth as has been pointed out before.[5] He can say further, that for certain depths, there are certain limits on the required magnitudes of the masses or magnetic bodies involved. With further information or assumption of density or magnetic contrasts, he can limit the size of the geologic deformation. Thus, if the physical data are to be translated into results useful for exploration, the geophysicist must either become geologist himself or confer with his geological partners to reduce the possible sources of the density or magnetic contrast to a useful exploration picture. If, as is too often the case, he has very little factual information, his interpretation, if he does more than draw an anomaly outline on a map, is based only on very general geological information and geological "reasonableness." At this stage he can hardly become a pioneer in exploration unless the limits imposed by physical analysis are such as to be outside the commonly accepted geological concepts of the area.

The most needed single item of control in connection with the geological in-

[5] D. C. Skeels; "Ambiguity in Gravity Interpretation;" *Geophysics XII*, 1 (January 1947) 43.

terpretation of gravity surveys is information on densities. Density contrasts are the fundamental cause of all gravity anomalies and without them no structure would produce a gravity disturbance. The properties of a gravity anomaly, its magnitude, form and extent, are a reflection of horizontal changes in density. Such changes may be produced by a structural disturbance of a sequence of beds between which there are differences in density, but they also may be produced by lateral changes in the lithology of a horizontal stratum.

There have been some attempts within individual oil companies to build up a body of information which would give data on the normal density sequence in an area. This is essentially a geological problem, but we do not have more than a bare beginning of reliable quantitative information of this kind. If field geologists could be induced to become density conscious and encouraged to include the density as an item of data about each surface or core sample examined, a substantial body of information could be built up which might, in time, have value to the geologist himself quite aside from its primary interest for geophysical exploration.

In some cases it may be possible to extend density information by establishing empirical relations between vertical velocities as found in well shooting and densities, but this must be done with care and could be misleading. Gravity surveys carried out in adequate detail over well known structures may give very useful general information but will give clear-cut and definite answers only in very favorable cases. An objective method of calculating densities in such cases, based on a least squares solution, has been pointed out by Hammer.[6]

The obvious direct answer, from a physical standpoint, is to devise a gravity measuring instrument which could be lowered into a well to make a vertical density log. This is technically difficult and, so far as the writer knows, has never been accomplished. Its value for gravity interpretation would certainly be considerable. With the new small and temperature compensated instruments the technical difficulties may be somewhat reduced and perhaps we can look forward to future developments of this kind.

REGIONAL GRAVITY AND REGIONAL GEOLOGY

The preceding comments are quite general and the problems of interpretation of potential fields are applicable to all anomalies, large or small. We usually think of such problems in connection with individual local, possibly oil bearing structures, but large scale features illustrate the same principles. Since many large features are widely known and have some stimulating relations to known geology, most of the specific examples discussed are taken from a comparison of large scale, or regional gravity features with regional geology.

The regional gravity map (Fig. 1) which is the basis for the comparisons of regional gravity with regional geology has been made available through the

[6] Sigmund Hammer; "A New Calculation Technique for Quantitative Interpretation in Gravity Prospecting" (Abstract Only) *Geophysics XII*, 3 (July 1947) 498.

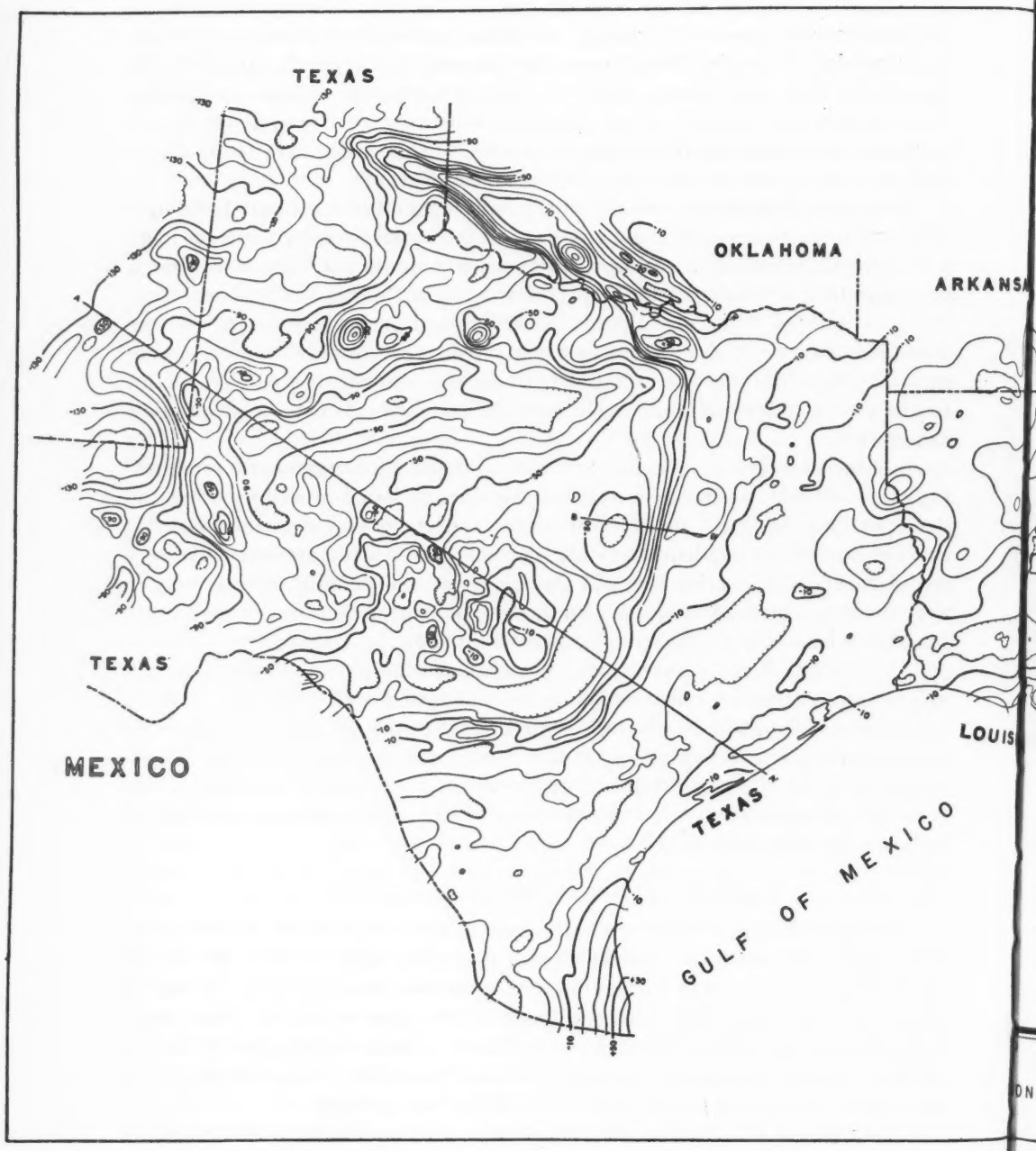
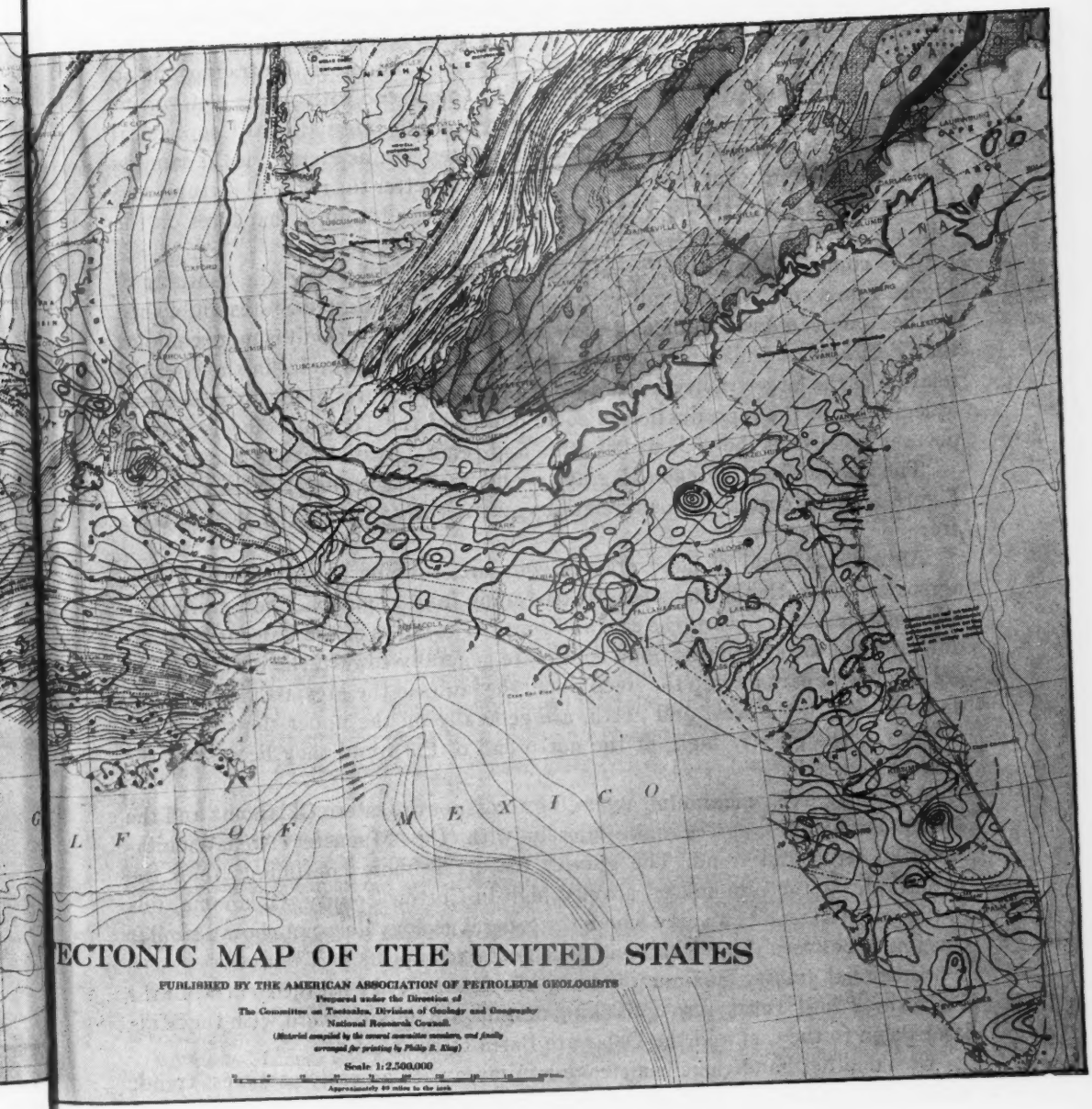


FIG. 1. Regional gravity map. Contours of Bouguer gravity at 10 milligal interval. Courtesy Humble Oil &

Oil & Co. and American Geophysical Union, Committee for Study of Continents, George P. Woollard, Chairman.

FIG. 2. Regional gravity contours of Figure 1 superimposed on Tectonic ma


ECTONIC MAP OF THE UNITED STATES
PUBLISHED BY THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
Prepared under the Direction of
National Research Council.
Scale 1:2,500,000
M E X I C O

United States, published by the American Association of Petroleum Geologists.

courtesy of the Humble Oil and Refining Company and the American Geophysical Union, Committee on the Study of Continents, George P. Woollard, Chairman. The original map was prepared by Dr. Woollard from the Humble Company assembly at 2 milligal contour interval and scale 1:1,000,000, by tracing the 10 milligal contours. From this, a map at scale 1:2,000,000 with 10 mg contour interval was prepared, which was first displayed at the International Geophysical Congress in Oslo August 1948. The map reproduced here as Figure 1 is the same as shown at Oslo except for re-drafting to emphasize better the regional features and to distinguish relatively high and low areas by the addition of hachures on the minima.

The combination map (Fig. 2) has been made by drawing the contours of Figure 1 on a copy of the familiar Tectonic Map of the United States, published by the American Association of Petroleum Geologists. The result is more complex than desirable and may be confusing but we hope will be useful in showing the relation of the large gravity features to the tectonic features of the area. The lack of legibility in the reproduction of some details of the Tectonic Map is not important because of the wide distribution and general availability of the original.

The comparison of regional gravity and regional geology, as is given by Figure 2, shows certain regional relations quite clearly. Among the most striking are:

An arcuate band of close gravity contours, running across central Texas, agrees closely with the Balcones-Mexia-Luling fault complex. The gravitationally positive side is toward the east and south. The faults of the Balcones system, downthrown toward the east and south, are generally toward the bottom of the gravity low or part way up the steep slope; the faults of the Mexia-Luling system, downthrown to the west and north, are generally on the upper slope and near the top of the gravity high; at the north end of the trend they lie east of the gravity high axis.

A strong gravity maximum, extending across southwestern Oklahoma and the Texas Panhandle, agrees quite closely with the Muenster Arch-Wichita-Amarillo structural trend. The gravity feature is more continuous than the structural, for the pronounced gravity high in Cotton County, Oklahoma, fills in the gravity trend in an area where the general geology does not show a similar continuity between the Wichita and Muenster Arch uplifts.

A regional gravity maximum is in rather close accord with the Central Basin Platform of west Texas; strong flanking minima are in fair accord with the Midland Basin to the east and the Delaware Basin to the west.

On the other hand there is a strong minimum with a nearly east-west trend, which extends for 300 miles across north-central Texas; a parallel line of round maxima lies just north of this trend. So far as we know, neither the large minimum nor the strong round maxima correspond with any disturbance of the sedimentary section.

In the eastern part of the map, the gravity features which correspond most

clearly with known tectonic features are in Central Alabama where the survey extends onto the southwesterly part of the Appalachian uplift. The gravity does not indicate, as might be expected, a definite continuation of the Appalachian structural trends southwesterly under the Cretaceous overlap.*

A sharp feature extending across northern Florida is closely parallel with the Applalachian trends but is not well supported by the pattern in the intermediate area so its relation to these trends is questionable.

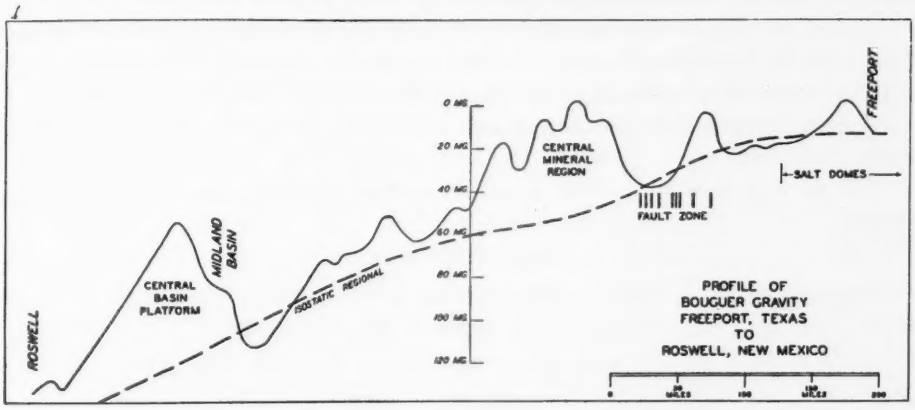


FIG. 3. Gravity profile across Texas, on line A-A′ of Figure 1.

Figure 3 shows a gravity profile along line *A-A′* of Figure 1 which extends from the Gulf Coast, near Freeport, Texas, northwesterly for 600 miles across Texas to Roswell, New Mexico. This profile shows the following prominent features:

A general gravity decrease toward the northwest. This is due to the isostatic compensation of the gradually increasing elevation, from sea level to over 4,000 feet.†

* We are not sure that a gravity expression of a continuation of the Appalachian trend should be expected. It may be that there are no strong density contrasts associated with the Paleozoic sediments and the metamorphic and igneous rocks exposed in the Appalachian mountains. Single gravity traverses in Pennsylvania[1] and West Virginia[2] indicated that such contrasts are not apparent. It would take a regional gravity map of part of the Appalachian area, preferably all of Northern Alabama, to determine whether or not clear gravity expressions of the Appalachian trends are present which might be expected to persist where the Paleozoic rocks are covered by the Cretaceous overlap.

[1] L. L. Nettleton, "Relation of Gravity to Structure in the Northern Appalachan Area," *Geophysics*, VI, 3, (July, 1941) pp. 270–286.

[2] Sigmund Hammer and E. T. Heck, "A Gravity-Profile Across the Central Appalachians . . ." *Trans. Am. Geophys. Union*, Part II (1941) pp. 353–362.

† It is generally recognized that very broad topographic features are quite completely compensated isostatically. This means that the sheet of material above sea level is compensated by a mass deficiency in the underlying part of the earth's crust. The gravitational effect of this mass deficiency is approximately the same as the Bouguer correction which is subtracted in the routine reduction of the gravity field observations. Therefore, the "isostatic regional" is approximated as the cumulative Bouguer correction for a smooth elevation curve representing the rise from the coast to the high plains of West Texas and New Mexico.

The maximum near Freeport, which is parallel with the coast is not related to regional geology within the explored section of the sediments so far as we know.

The steep gravity maximum with a broad minimum to the west is the arcuate feature which corresponds approximately with the fault zone for hundreds of miles. The positions of the Balcones type faults (hachured on the right side) and Luling type faults (hachured on the left) are indicated.

A strong high with superimposed smaller irregularities, corresponds generally with the Central Mineral Region.

A deep minimum corresponds in part with the northern end of the Midland Basin, but it is modified by the western end of the previously mentioned large gravity minimum of unknown cause, extending across north-central Texas.

A very large maximum corresponds with the northern end of the Central Basin Platform.

Let us turn now to a more detailed consideration of a few of the features shown:

THE FAULT ZONE:

Figure 4 shows a more detailed profile of the gravity anomaly across the Balcones-Luling fault complex just south of Waco (line *B-B'* of Fig. 1), taken from the original gravity map with 2 mg contour interval. This shows a gravity

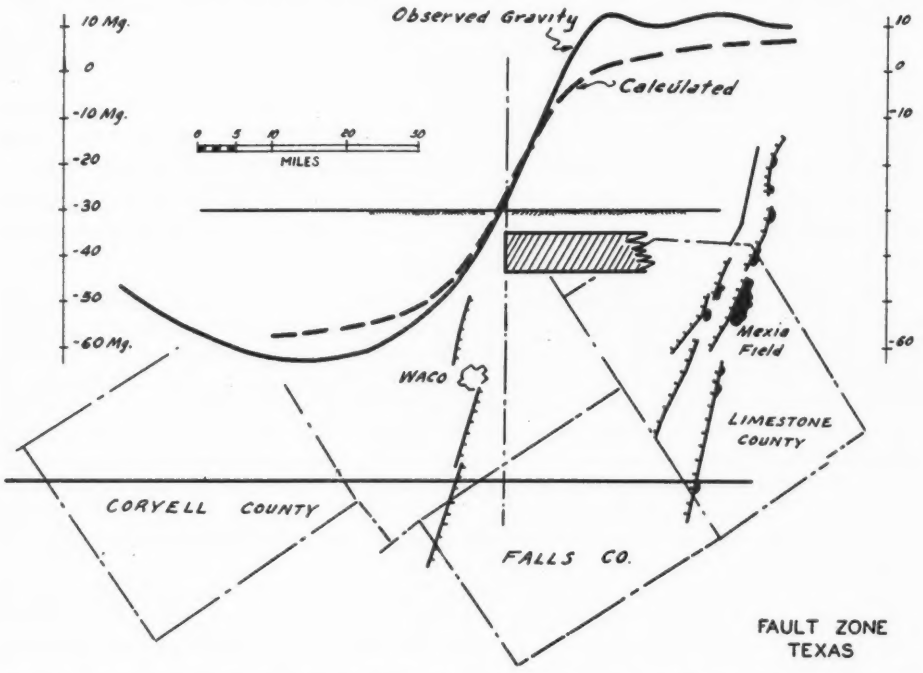


FIG. 4. Gravity profile across Balcones-Mexia fault zone, on line B-B' of Figure 1, with calculated gravity effect from assumed block shown. Horizontal and vertical scales equal.

relief of about 70 mg. As a basis for initial speculation about the cause of the gravity feature, we have calculated the effect, shown by the dashed curve, from a fault-like contact shown as the shaded block in the cross section. The mean depth is 5.5 miles; the thickness, for a density contrast of 0.2 is also about 5.5 miles. A higher density contrast would reduce this thickness. A more detail study could add some details but the general orders of magnitude of limiting depth and thickness are fixed. To advance the analysis, the geophysicist must become a geologist. What is a reasonable density contrast? What rock types in the depth range required could be responsible for this contrast? What type of movement within the earth's crust could bring this density contrast into being? When could such movement have occurred and how is it related to the zones of faulting which we know within drilling depths? Some very profound disturbance is clearly indicated by the strong gravity anomaly and the close coincidence in position implies a close causal relation to the fault zone.

It has been suggested that this disturbance is similar to the island arcs of the West Indies.[7] The radius of curvature, about 200 miles, is only a little less. The gravity disturbance in Texas has only about half the relief and the form is quite different as the principal characteristic of the island arc anomaly is a gravity trough with a depth of about 150 mg.

It may be reasonable to guess that the present gravity feature is an old Paleozoic (?) anomaly of the island arc type but now considerably modified and reduced in magnitude by later movement and isostatic adjustment since it was originally formed. The approximate coincidence of the Llanoria Geosyncline[8] with the arc of faults and the gravity feature may lend support to this guess. We would then guess, further, that the Llanoria Geosyncline originated in a "tectogene" similar to that of the present West Indies island arc, of which only part of the original underlying deep crustal deformation still persists so that a considerably reduced and modified gravity expression is shown at the present time. It is obvious that, in making these speculations, the geophysicist is turning geologist and needs the help of his geological associates.

Certain limitations on the dimensions of the geological disturbance such as suggested above can be imposed by analysis of the gravity indications. Given these physical limits the geologist must begin to answer the geophysicist's questions. A congenial and inquiring passing of these questions back and forth from one to the other until an answer satisfactory to the geologist in terms of the general nature of the rocks and processes involved, and satisfactory to the geophysicist in terms of the quantitative restrictions on the magnitude, position and form of the density contrasts required, should lead to a distinct advance in our understanding of the profound disturbances of the earth's crust which must

[7] H. H. Hess, "Gravity Anomalies and Island Arc Structure," *Proceedings of the American Philosophical Society*, 79, 1 (April 21, 1938), 71–96.

[8] See, for instance, Index Map for El Paso Meeting, *Bull. A.A.P.G.*, 24, No. 1 (Jan. 1940), 2, 3.

be responsible for this arcuate gravity feature extending some 500 miles across the middle of Texas.

THE AMARILLO-WICHITA UPLIFT

A profile across this large uplift indicates a gravity relief of around 70 mg and a form which can be accounted for by an uplifted block, the size estimates of which, again, must be contingent on assumptions as to density contrasts. If we assume that such a block comes substantially to the surface, it would be approximately 20 miles wide and would have its base at a depth of approximately 5 miles for a density contrast of, say, 0.25; the depth to the bottom would be more or less than this figure depending on whether the density contrast is less or more than that assumed. A deeper, thicker and narrower block also could be fitted to the observed curves. The possible dimensions of such blocks give certain limits which physical analysis can place on the cause of this feature. To make such estimates useful we must turn to the geologist and ask what type of rock could produce such contrasts? What densities might be involved? What process raised up this huge block of material? Here again the complete answer requires a passing of facts and assumptions back and forth between geophysicist and geologist until answers compatible with the limits imposed by both can be achieved.

THE CIRCULAR GRAVITY MAXIMA:

The map, Figure 1, shows several large circular gravity maxima, from Texas to Georgia, with gravity relief of 30 to 60 mg. Particularly conspicious examples are: the well known Crosbyton high, centering in southeastern Garza County, Texas; a somewhat smaller one, centering in southeastern Knox County, Texas; the Logansport high on the Texas-Louisiana line; the Jackson high centering at Jackson, Mississippi; and two very strong circular anomalies in southern Georgia. While they differ considerably in detail, all of these features are of a general nature which could be caused by more or less circular, plug-like density contrasts. The gravity relief is such that they can hardly have their origin within the sediments because the required mass anomaly is so large that no reasonable assumption as to density contrasts would admit the required volume of anomalous material within the sedimentary section. Therefore, we can say that the gravity disturbances must be caused principally by density contrasts within the basement rocks. We cannot, on physical evidence alone, say that the density contrasts are confined entirely to the basement because analysis of the various possible forms of the mass which could cause the gravity anomaly could not distinguish between an origin entirely within the basement and one largely within the basement but with a contribution from a coincident uplift of the overlying sediments. Therefore, the geophysicist, as an unaided physicist, cannot tell whether such features are of interest as possible causes of sedimentary structure or not.

The Crosbyton anomaly has been tested by several wells and does not correspond with a large structure. On the other hand, the Jackson high corresponds

with an uplift that dominates the structural pattern of several counties in southern Mississippi. The Logansport high apparently has some associated uplift. Is there any geological theory which could have predicted these relations? These circular highs may be of volcanic origin, but we do not know. If they are of volcanic origin, the time of their occurrence would be of prime interest in evaluating their possible effect on overlying sediments. If volcanic materials, such as ash or flows, are known to exist in the sediments around areas where there are pronounced circular gravity highs, may we presume that these highs are caused by disturbances occurring during the time of the sediments carrying such volcanic material? Is the absence of any volcanic material in the section a criterion by which we could safely ignore this type of anomaly as a possible indication of sedimentary structure? A gravity survey around the Paricutin Volcano in Mexico does not show a simple anomaly that can be definitely correlated with the volcano there.[9] Are there other processes taking place in igneous rocks which can produce these strong circular gravity features and if so are there any means of determining the geological time at which such process may have occurred? These are geological questions which are intimately related to the evaluation of this type of geophysical feature, but which are outside the usual field of the geophysicist.

REGIONAL GRAVITY ANOMALIES OF A SALT DOME AREA

Gravity surveys along the Gulf coast and in Mississippi, northern Louisiana and northeast Texas have covered areas which include salt basins. There has often been speculation as to whether or not the limits of salt basins could be determined by regional gravity pictures. Apparently the idea has been prevalent that the existence of a thick layer of salt would make a recognizable gravity anomaly. Quantitative considerations show this to be improbable. With reasonable assumptions of probable density contrasts, a sheet of salt 1,000 feet thick would produce a relative deficiency of gravity of around 4 mg. If a salt layer were 2,500 feet thick, its gravity effect would correspond to only one contour interval of the map shown. Also, the changes in thickness at the edge of such a sheet probably would be spread over a few miles laterally. It is quite obvious, from the regional gravity map of Figure 1, that there are other disturbances of very much greater relief and it would be very difficult to recognize the direct gravity effect of the salt among these other and stronger regional features. Moreover, a brief consideration of the regional map shows that general relations do not fit into the expected pattern. The South Mississippi salt dome basin is generally in a gravitationally high area. The gravity low to the south of it is in the region of no domes between the Mississippi and Gulf coast salt dome areas.

The question of the possible regional structural significance of some of these

[9] Virgil E. Barnes and Frederick Romberg, "Observation of Relative Gravity at Paricutin Volcano," *Bulletin of the Geological Society of America*, 59, No. 10 (Oct. 1948), 1019–1025.

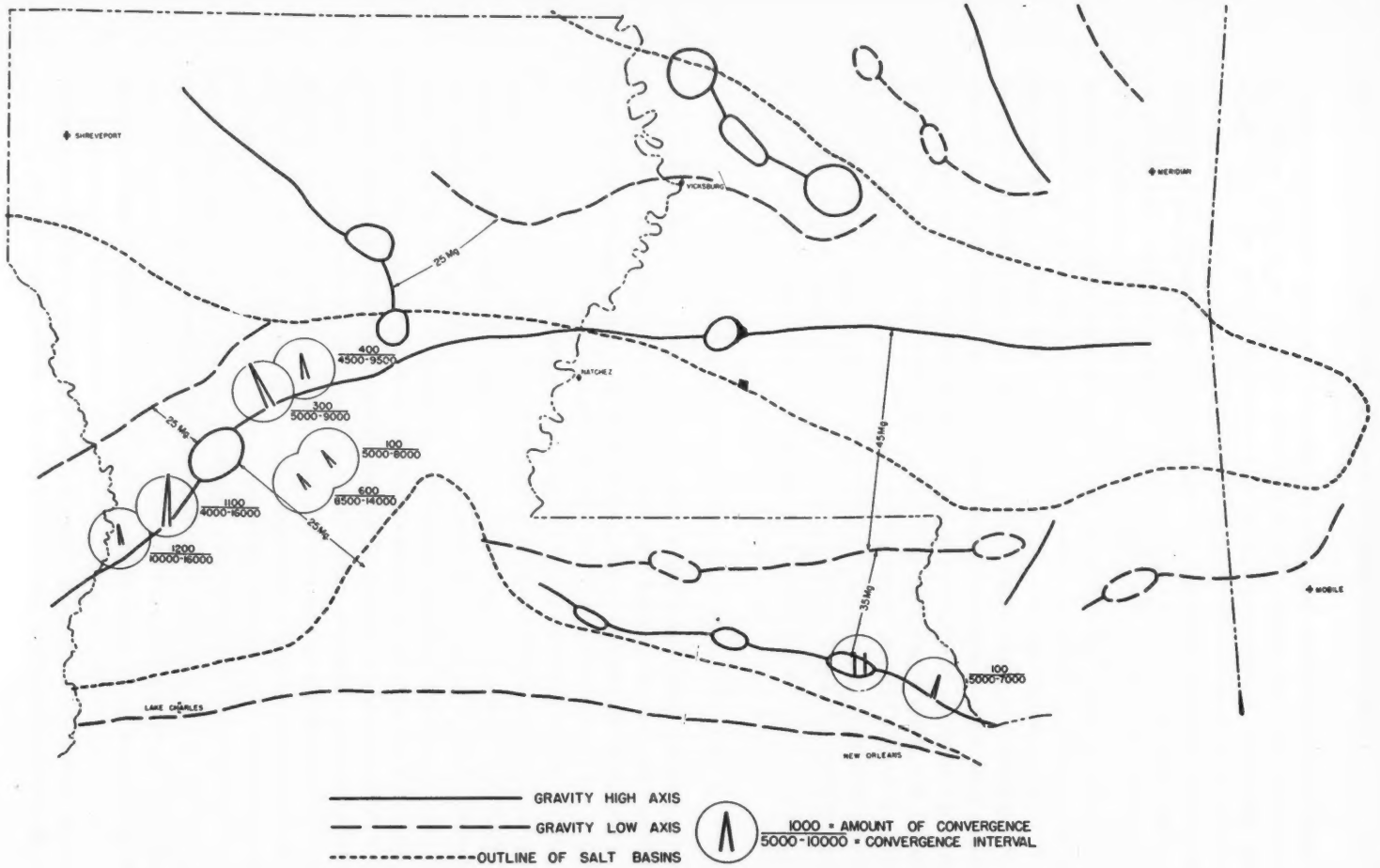


FIG. 5. Gravity maximal and minimal axes, Louisiana and southern Mississippi. Direction of convergence from seismograph maps shown by V-symbol. Upper figure indicates amount of convergence, in feet, across area represented by each symbol; lower figures indicate approximate depth of horizons between which convergence was measured.

large features need not be left entirely unanswered when we take advantage of other information. Figure 5 illustrates a possible approach which was applied to a region including the salt dome areas of Mississippi, northern Louisiana and part of the Gulf coast and the intermediate areas barren of domes. We are indebted to the Gulf Oil Corporation for the preparation and release of the map showing these features.

The axes of several regional maxima and minima within the south Mississippi salt basin and adjacent areas are shown in Figure 5; the gravity features themselves will be recognized on the map, Figure 1. If regional structural disturbances corresponding to these axes extend upward into the sediments, we should be able to detect them by consideration of broad geological patterns, such as changes in direction and rate of convergence. In this area, a convergence study was made by the use of spotted local seismograph surveys for which maps had been made on two or more horizons. By taking the differences between the highest and lowest horizon mapped, the direction and rate of the over-all convergence was determined for each local area and is displayed by a suitable symbol on the map (Fig. 5). These symbols should indicate any broad disturbance of the sedimentary section within the depth thus explored. However, the convergence study showed quite uniform coastward thickening of the sediments, with no definite relation between the magnitude and direction of convergence and the positions of positive or negative gravity axes. In this case, the use of results from another geophysical method enables us to rule out these regional gravity axes as factors in the regional sedimentary geology of the area to the depth explored by this seismograph work, which, in some cases, was as much as 16,000 feet.

A PUZZLING GRAVITY MINIMUM

Through the courtesy of Trinidad Petroleum Development Company, we can consider a particularly impressive example of a local specific geological problem posed by a geophysical result. This is furnished by the extremely sharp, circular, 6 milligal gravity minimum shown by Figure 6 which was found over an area of mud volcanoes in Trinidad. If the picture were inverted its size and form would closely resemble those of some of the most intensive positive anomalies over shallow cap-rock of Gulf Coast salt domes.

Its explanation requires a strong, circular negative density contrast, at shallow depth. If the top of the mass anomaly were close to the surface, it would require a thickness of about 650 ft. and a diameter of about 1½ miles for a density contrast of one C.G.S. unit. A lower density contrast would require a greater thickness. A deeper, more plug-like form also could account for the feature. It could hardly be a salt dome such as we know in the Gulf Coast because the required density contrast at shallow depth is too great.

The mud volcanoes are gas seeps which bring up substantial volumes of mud. It was suggested that the minimum represents a pitch lake (the famous Trinidad Pitch Lake at Brighton is a gravity minimum of about 3 mg. relief), but there is no

Upper figure indicates amount of convergence, in feet, across area represented by each symbol; lower figures indicate approximate depth of horizons between which convergence was measured.

pitch or oil with the gas and mud and no mud flow at the Pitch Lake. How could the mud be brought up through a body of pitch without some of the pitch being brought to the surface? If not pitch, what could make the density contrast? Is the mud of low density, perhaps "gas cut," and in a long vertical pipe with a diameter of about 2,000 to 3,000 feet? What are the other geological possibilities? Here is a new and quite unexpected geophysical picture, which, when explained will almost certainly bring about modification of present theories and a better

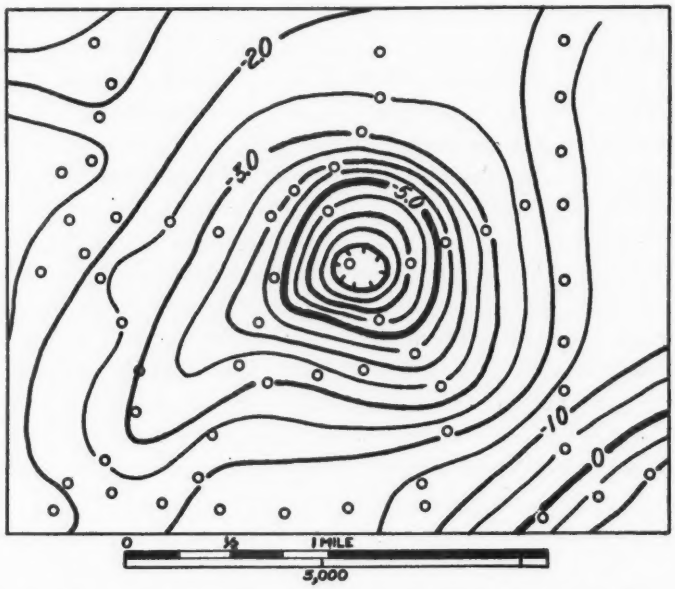


FIG. 6. Residual gravity map over an area of mud volcanoes in southern Trinidad. Contour interval 0.5 mg. Total relief about 6 mg. Courtesy Trinidad Petroleum Development Co.

understanding of mud volcanoes. The next step is a geological one to suggest possibilities within the limits imposed by the physical facts.

CONCLUSION

Probably most geologists and geophysicists, who have looked at broad scale gravity and magnetic maps have been tempted to interpret them in terms of broad tectonic features which would have effects on the sedimentary geology and therefore would be of interest in oil exploration. Such temptations must be tempered by the quantitative control which the geophysicists can supply and by experience in actual relations between the gravity and tectonic data of the kind which is given by the comparison or superposition of the two kinds of maps as shown, for example, by Figure 2. We then find many cases of close coincidence. We also find many cases where strong gravity features, some of which are clearly regional and some relatively local, have no counterpart in the geology that we

know. It would be a distinct step if we would discover, through broad geological and geophysical thinking, any criteria which would serve as a basis for distinguishing those geophysical features which arise from disturbances which may have affected the sediments and those which have not.

Such criteria, if we find them, will depend upon the quantitative control which can be given by the geophysicists and by the factual control and guessing as to possible sources which must be furnished by geologists, together with an active imagination by both, and a sympathetic consideration of each other's view point. Also in the interpretation of individual local anomalies, the geophysicist can supply certain limits of location, size and depth, but the geologist must then give his help.

When team work between geologists and geophysicists has reconciled all the known items of data with each other and with reasonable speculations, we may approach much more clearly a picture of the geologic past as reflected in present geophysical and geological facts. In this way we can hope to advance beyond geological and geophysical guesses, and let fact keep our feet on the ground when we are tempted to indulge in flights of uninhibited fancy for, as the poet says:

> *"Ah what avails the classic bent,*
> *And what the cultured word*
> *Against the undoctored incident*
> *That actually occurred"*[10]

[10] Rudyard Kipling "The Benefactors" first stanza.

THE DIRECT APPROACH TO MAGNETIC INTERPRETATION AND ITS PRACTICAL APPLICATION*

LEO J. PETERS†

ABSTRACT

This paper discusses the solution of the inverse potential problem and its practical application in the interpretation of field data which have a scalar potential distribution. The discussion will be in terms of the interpretation of magnetic data. Among the topics discussed are: the direct calculation of basement relief, the derivation of the potential and the horizontal components of the field from the vertical intensity, the continuation of the field upward, the continuation of the field downward towards its source, the calculation of derivatives of the vertical intensity with special attention to the second and fourth, and the estimation of depths to igneous basement rocks. The uses of these tools and the information of practical value which can be obtained by their use are discussed and illustrated. Methods of rapidly making calculations using magnetic field data are given.

Several volumes could be written on the subject of the interpretation of gravity and magnetic data. It is therefore a difficult task to write a single paper covering the subject, and severe limitations must be placed on the choice of topics to be covered and the detail in which they are discussed. This paper will present and discuss some of the special methods developed at Gulf Research Laboratories starting some nineteen years ago to aid in an interpretation of magnetic and gravity data. The discussion will be in terms of magnetic interpretation and functions, but its extension to the gravitational case can be made in most cases as both are potential fields.

In 1929 when the writer joined the Gulf organization, it was common practice to make gravity and magnetic calculations by assuming a distribution of mass or of magnetic material, calculating the field due to this assumed distribution, and modifying the distribution until the calculated field fit as closely as desired the observed data. We at the Gulf Laboratories undertook to solve the inverse problem. That is, we started with the observed field and undertook to calculate directly a distribution of matter that would account for this field. Unfortunately, this problem has no unique solution. It can be made unique only by making assumptions as to the nature of the distribution causing the field. It is our inability to know just what these assumptions should be that leads to the ambiguity in the interpretation of gravity and magnetic data. This lack of uniqueness applied also to the indirect method of interpretation and the direct method of attack—as we shall show—led to some powerful tools which are an aid in the solution of the uniqueness problem.

As happens at all large research institutions, the solution of a problem is carried forward by team work among a group of individuals. In addition to the

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† Gulf Research & Development Company, Pittsburgh, Pennsylvania.

writer, those who contributed to the development of the material covered in this paper are: John Bardeen, H. M. Evjen, T. A. Elkins, James Affleck, and H. H. Evinger. Of those mentioned, the contribution of John Bardeen was outstanding. The writer wishes to express his appreciation to Messrs. Affleck and Elkins for their aid in preparing the present paper.

The problem of magnetic interpretation is to deduce geological subsurface information from magnetic measurements made at the surface or above the surface of the earth. In most cases, but not in all, the sediments are made up of non-

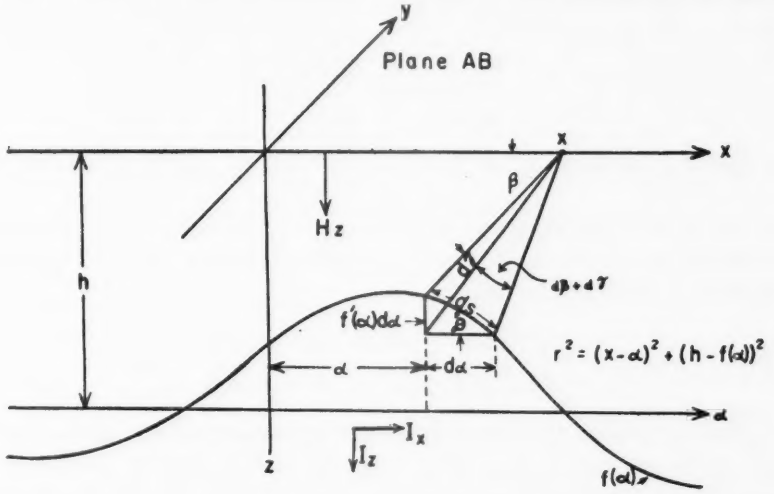


FIG. 1. Plane AB on which measurements of the vertical intensity of the magnetic field have been made.

magnetic rocks, so in most areas the problem of magnetic interpretation is to deduce as much information as possible concerning the nature and the attitude or convolutions of and the depth to the igneous basement rocks.

As stated above, the problem of the direct calculation of the distribution of magnetic material from the observed field was attacked in 1929. By the first part of 1930, direct two-dimensional structure calculations were being made as a routine matter of interpreting field data. This early solution of the direct calculation of structure is given in sketch form below:

In Figure 1, AB is a plane on which measurements of the vertical intensity of the magnetic field have been made. The curve centering on the line $z=h$ represents the convolutions of the magnetically active rocks, which are assumed to have a constant polarization. The contribution of the element ds to the vertical intensity, $H_{z_1}(x)$, at x is:

$$dH_{z_1}(x) = -2\left[-I_x \cos\theta + I_z \sin\theta\right]\frac{\sin\beta}{r}\cdot ds. \qquad (1)$$

Now Equation (1) can be written in the form

$$dH_{z_1}(x) = 2I_z(d\beta + d\gamma) + 2I_x f'(\alpha)\frac{h - f(\alpha)}{r^2}d\alpha. \tag{2}$$

Since

$$\frac{\cos\theta \sin\beta ds}{r} = (d\beta + d\gamma), \qquad \sin\theta ds = -f'(\alpha)d\alpha,$$

and

$$\sin\beta = \frac{h - f(\alpha)}{r}.$$

The sign of $d\gamma$ is the same as the sign of $(x-\alpha)f'(\alpha)$ and is negative in Figure 1.

Now the term $2I_z d\beta$ integrates to $2\pi I_z$ since I_z is constant and represents the vertical field if no structure is present. If this constant term is disregarded the anomaly field is given by the relation

$$H_z(x) = 2\int_{-\infty}^{\infty} \frac{I_z(x-\alpha) + I_x(h - f(\alpha))}{(x-\alpha)^2 + (h - f(\alpha))^2} f'(\alpha)d\alpha. \tag{3}$$

Equation (3) relates the vertical magnetic intensity on the plane AB to the structure of the magnetic rocks producing the field. It may be considered as an integral equation for determining $f(\alpha)$ when $H_z(x)$ is known. The integral equation is nonlinear. It can be made linear under the condition that the structure is small compared to the depth of burial, that is if $f(\alpha) << h$.

Since our magnetic data were known only at discrete points along AB, the equation was solved under the condition $f(\alpha) << h$ by replacing the integral by the sum

$$H_z(x_j) = 2\sum_{i=-n}^{i=+n} \frac{I_z(x_j - \alpha_i) + I_x h}{(x_j - \alpha_i)^2 + h^2} a_i \tag{4}$$

where

$$a_i = \{f'(\alpha)d\alpha\}_i.$$

For the case in which the rocks are vertically polarized only, the solution takes the form

$$a_0 = \frac{b}{2I_z}\sum_j B_j(H_{+j} - H_{-j}). \tag{5}$$

Table I gives a set of coefficients B_j to use with this equation; all measurements are in terms of the depth of burial where b is the separation between points

Table I

Two Dimensional Structure Coefficients

$$a_0 = \frac{b}{2I_z} \sum_j B_j (H_{+j} - H_{-j})$$

$(H_{+j} - H_{-j})$	B_j	$(H_{+j} - H_{-j})$	B_j
$H_{+\frac{1}{2}} - H_{-\frac{1}{2}}$	1.86864	$H_{+8} - H_{-8}$	0.04307
$H_{+1} - H_{-1}$	−0.62953	$H_{+10} - H_{-10}$	0.21834
$H_{+2} - H_{-2}$	0.09034	$H_{+12} - H_{-12}$	−0.18946
$H_{+3} - H_{-3}$	0.00850	$H_{+15} - H_{-15}$	−0.01879
$H_{+4} - H_{-4}$	0.01505	$H_{+18} - H_{-18}$	−0.01504
$H_{+5} - H_{-5}$	0.00088	$H_{+24} - H_{-24}$	−0.00526
$H_{+6} - H_{-6}$	0.04647		

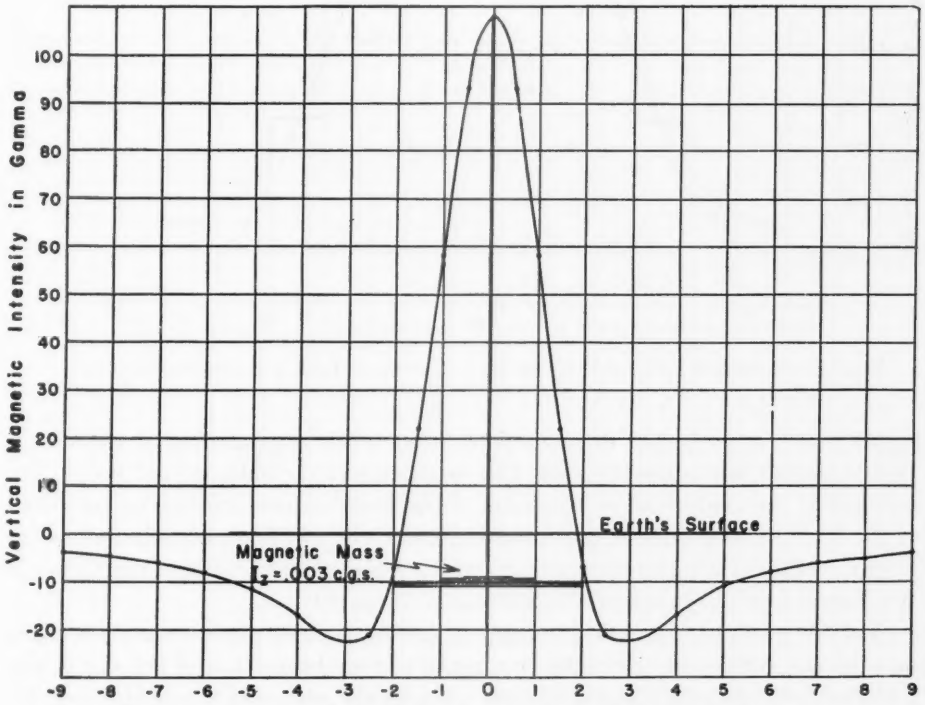


FIG. 2. A structure and the calculated magnetic anomaly produced by it.

at which calculations are made. The quantity a_0 gives the rise of the structure between two consecutive points as this quantity represents $f'(x)dx$. Figure 2 shows a structure and the calculated magnetic anomaly which it produces. Figure 3 shows the structure as calculated by using the coefficients of Table I and this magnetic curve.

We next proceed to show how, given the magnetic intensity on the surface of the earth or on a plane above the earth, the intensity can be projected upward to

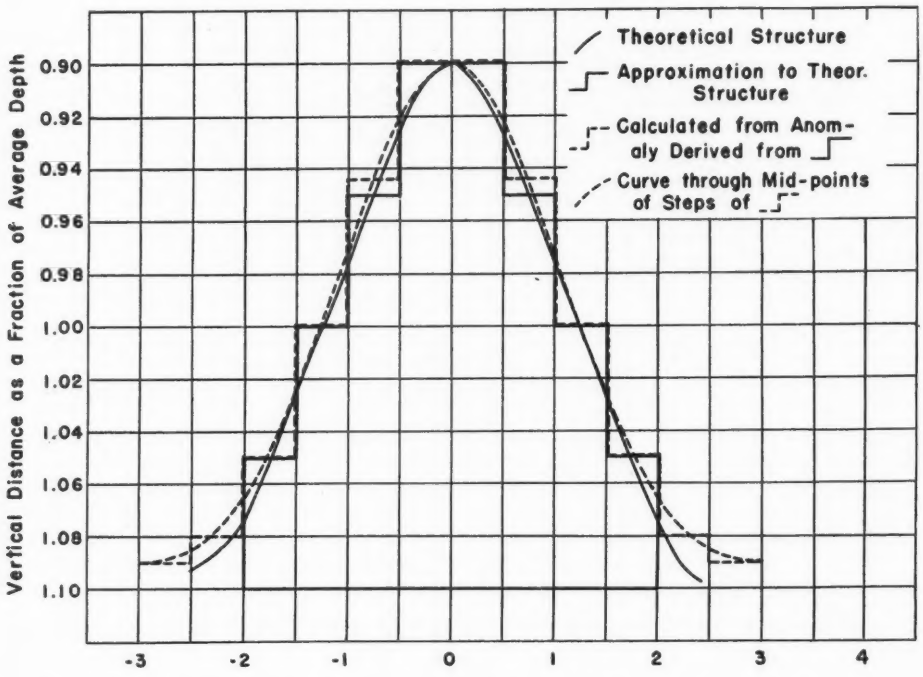


FIG. 3. Structure as calculated by using the coefficients of Table I and the magnetic curve.

higher levels or projected downward to lower levels approaching or coincident with the rocks producing the field. The projection of the field upward is old. The problem of the analytical continuation of the field towards its source was solved at the Gulf Laboratories in late 1930 and early 1931. It is a valuable tool in the interpretation of all geophysical data which have a potential field distribution. We discuss first the problem of continuation upward.

Let the vertical magnetic intensity be known on any plane $z=0$. This plane may be the surface of the earth or a plane above the surface of the earth. Let z be positive downward in a direction towards the source of the field. Then the continuation upward away from the source of the field is given by the well-known equation:

$$H_z(x, y, z) = \frac{-z}{2\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \frac{H(\alpha, \beta, o)d\alpha d\beta}{[(x-\alpha)^2 + (y-\beta)^2 + z^2]^{3/2}}; \qquad z \gtrless o. \tag{6}$$

Since the measured field is not known as a mathematical function, we wish to devise a practical scheme for the numerical evaluation of the integral. We proceed as follows:
Let

$$\alpha - x = r\cos\theta; \qquad \beta - y = r\sin\theta$$

$$\overline{H}_z(r) = \frac{1}{2\pi}\int_0^{2\pi} H_z(r, \theta)d\theta$$

$$H_z(x, y, z) = -\int_0^{\infty} \frac{\overline{H}_z(r)zrdr}{(z^2 + r^2)^{3/2}} \tag{7}$$

where $\overline{H}_z(r)$ is the average value of $H_z(\alpha, \beta, o)$ around a circle of radius r centered at $(x, y, 0)$.

Let the height of the continuation upward be $z = -h$. Then Equation (7) becomes:

$$H_z(x, y, h) = \int_0^{\infty} \frac{\overline{H}_z(r)hrdr}{(h^2 + r^2)^{3/2}}. \tag{7a}$$

The integral is replaced by the sum

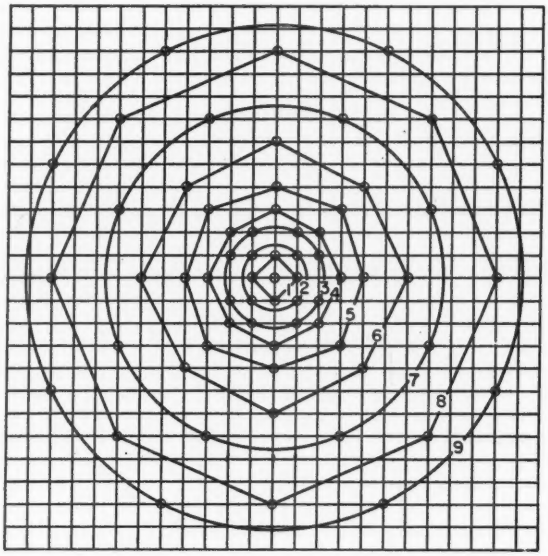
$$H_z(x, y, h) = \frac{\overline{H}(o) + \overline{H}(b_1)}{2}\int_0^{b_1} \frac{hrdr}{(h^2 + r^2)^{3/2}} + \frac{\overline{H}(b_1) + \overline{H}(b_2)}{2}\int_{b_1}^{b_2} \frac{hrdr}{(h^2 + r^2)^{3/2}} + \cdots \text{etc.} \tag{7b}$$

Upon carrying out the integration and collecting terms, this becomes:

$$\overline{H}_z(x, y, h) = \frac{\overline{H}(o)}{2}\left[1 - \frac{h}{(h^2 + b_1^2)^{1/2}}\right] + \frac{\overline{H}(b_1)}{2}\left[1 - \frac{h}{(h^2 + b_2^2)^{1/2}}\right] + \frac{\overline{H}(b_2)h}{2}\left[\frac{1}{(h^2 + b_1^2)^{1/2}} - \frac{1}{(h^2 + b_3^2)^{1/2}}\right] + \frac{\overline{H}(b_3)h}{2}\left[\frac{1}{(h^2 + b_2^2)^{1/2}} - \frac{1}{(h^2 + b_4^2)^{1/2}}\right] + \cdots \text{etc.} \tag{8}$$

Magnetic data are generally presented in the form of a map with readings on some sort of a grid. Let the grid of Figure 4 represent such a map with the vertical intensity values known at every corner. The continuation upward is to be calculated at the point "o." It is convenient to use the grid spacing as the unit of measure. In this measure draw a circle of radius unity around the point o. Four

magnetic values fall on this circle, and the average value around the circle of $\overline{H}_z(b_1)$ is the sum of these four values divided by four. If the intensity is to be calculated one unit above the plane $z=0$, then $h=1$, $b_1=1$ and the term multiplying $\overline{H}_z(o)$ is $\frac{1}{2}[1-(1/\sqrt{2})]=0.1464$. Next draw a circle with radius $\sqrt{2}$ about o. Four values lie on this circle and $\overline{H}(b_2)$ is one-fourth the sum of these four values and $b_2=\sqrt{2}$. The term multiplying $\overline{H}(b_1)$ is $\frac{1}{2}[1-(1/\sqrt{3})]=0.2113$. The value of b_3 is taken as $\sqrt{5}$. Referring again to Figure 4, the circle of radius b_3 passes



Circle No.	Average Radius
0	0
1	1
2	$\sqrt{2}$
3	$\sqrt{5}$
4	$\sqrt{8.5}$
5	$\sqrt{17}$
6	$\sqrt{34}$
7	$\sqrt{58}$
8	$\sqrt{99}$
9	$\sqrt{125}$

FIG. 4. Chart for evaluating $\overline{H}(r)$.

through the eight points on the corners of the octagon and the values at these eight points are used to obtain the average value of $\overline{H}(b_3)$ on the circle for which $b_3=\sqrt{5}$. The grid of Figure 4 shows the octagons connecting points whose values are used in obtaining the average values of the intensity on successive circles. Some of the points used do not fall exactly on circles. In those cases, the average distance to the points on the octagon is used as the radius.

Table II gives two sets of coefficients to be used with this chart. One set is for continuation upward a distance of one grid spacing (two of these coefficients were calculated above) and the other for continuation up a distance of two grid spacings. In practice, an opaque card is placed on the map from which calculations are being made. The card has openings exposing the numbers which fall at the points used in the calculations. The computer runs off the sums for each circle on an adding machine. The coefficients are divided by a number equal to the number of points on the associated octagon so the sums can be used directly to multiply these divided coefficients. The coefficients for continuation upward

should add to unity. The coefficient for the largest circle is adjusted in the sets given to meet this requirement.

The grid and coefficient system of evaluating the surface integral for continuation upward has been discussed here because the same method can be used for making many of the calculations presented in this paper.

In the above discussion, $\overline{H}(r)$ was considered a constant over each interval of integration. More accurate coefficients may be obtained by interpolation formulae for $\overline{H}(r)$. For instance, $\overline{H}(r)$ might be considered linear between b_i and

Table II

Coefficients for Continuation Upwards

$$H_0(-h) = \sum \overline{H}(n) b_n$$

Circle No.	Average Radius	b_n for height h = 1 spacing	b_n for height h = 2 spacings
0	0	.1464	.0528
1	1	.2113	.0918
2	$\sqrt{2}$	.1494	.1139
3	$\sqrt{5}$	.1264	.1153
4	$\sqrt{8.5}$	.0862	.1151
5	$\sqrt{17}$	.0778	.1207
6	$\sqrt{34}$	.0528	.0902
7	$\sqrt{58}$	.0346	.0637
8	$\sqrt{99}$	.0206	.0400
9	$\sqrt{125}$	.0949	.1965

Coefficient for 9th circle is obtained by subtracting the sum of the first nine coefficients from unity.

b_{i+1} or may be represented by a second order equation over each of these intervals.

CONTINUATION DOWNWARD

The anomalies in the magnetic field of the earth may be considered as arising from two causes, lateral changes in the magnetic polarization of the basement rocks and the topography or structure of the basement surface. It is topography of the basement surface and its depth that is of importance in oil exploration. Before structure calculations can be made, the field due to changes in polarization must be removed. When the basement rocks are buried one mile or more, the anomalies due to oil structure are of the order of 0 to 150 gamma, with most of them lying below 50 gamma. At the same depth of burial, polarization anomalies may have a relief of several thousand gamma with the majority being of the order of several hundred gamma or lower. There is no unique criterion for removing the field due to polarization changes. However, if we could calculate the

field at a level near or on the basement surface, we would increase the relief of the magnetic field over sharp structures greatly while increasing the relief over broad polarization changes but little. Anomalies would also be separated more clearly and their individual study made easier. We therefore proceed to give the solution of the problem of analytic continuation downward. In addition to enabling us to calculate the field near the basement surface from measurements made at the surface, it is also the key to the complete solution of the inverse potential problem. That is, it enables us to calculate directly from the field observed at the surface a distribution of magnetically active rocks which will account for this field.

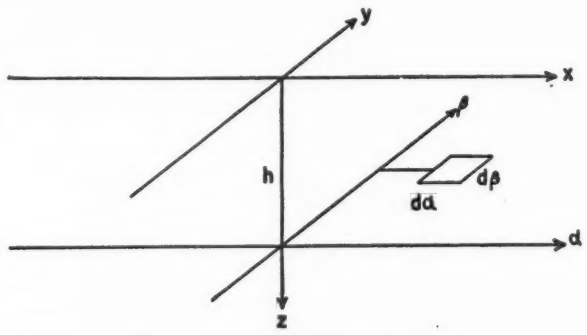


FIG. 5. Continuation downward.

The problem of analytical continuation downward towards the source of the potential field has been solved in a number of ways. In Figure 5 let the vertical component of the magnetic intensity on the plane $z=h$ be represented by $F(\alpha, \beta)$. To calculate the field at planes above $z=h$, this field can be considered as replaced by a vertically polarized plane in which the polarization is $H(\alpha, \beta)$ divided by 2π. We therefore write

$$H(x, y) = \frac{1}{2\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \frac{hF(\alpha, \beta)d\alpha d\beta}{[(x-\alpha)^2 + (y-\beta)^2 + h^2]^{3/2}}. \tag{9}$$

This equation is identical with Equation (6) for continuation upward. It may be considered as an integral equation for determining $F(x, y, h)$ given $H(x, y, o)$. This integral equation was solved at the Gulf Laboratories in the Fall of 1930 by an application of Fourier's Integrals and by a method of successive approximations. It can also be solved by replacing the integral equation by an associated set of linear algebraic equations.

In January, 1931 the problem of analytical continuation was solved at the Gulf Laboratories by the use of Taylor's Expansion. Since this is by far the simplest method of solving the problem and the solution is readily amenable to numerical calculations from the type of data obtained in gravity or magnetic surveys, it is the method which will be discussed here.

Since the vertical magnetic intensity is analytic in the space above magnetic rocks, which we will consider to be the igneous basement rocks, this intensity may be expanded in terms of the intensity on the surface of the earth in the form

$$H(x, y, h) = H(x, y, o) + hH^{I}(x, y, o) + \frac{h^2}{2!} H^{II}(x, y, o)$$

$$+ \frac{h^3}{3!} H^{III}(x, y, o) + \cdots \text{etc.} \tag{10}$$

where $H^{I}(x, y, o)$ represents

$$\frac{\partial H}{\partial z}(x, y, z)$$

taken at $z=o$.

There are several ways of calculating the derivatives in Equation (10). Since the calculation of even derivatives is more direct than the calculation of odd derivatives, we proceed as follows to obtain an expansion in terms of even derivatives. The continuation upward to a height $z=-h$ can be written

$$H(x, y, -h) = H(x, y, o) - hH^{I}(x, y, o)$$

$$+ \frac{h^2}{2!} H^{II}(x, y, o) - \frac{h^3}{3!} H^{III}(x, y, o)$$

$$+ \frac{h^4}{4!} H^{IV}(x, y, o) + \cdots \text{etc.} \tag{11}$$

Upon adding Equations (10) and (11) and solving for $H(x, y, h)$, we obtain:

$$H(x, y, h) = - H(x, y, -h) + 2\left[H(x, y, o) + \frac{h^2}{2!} H^{II}(x, y, o)\right.$$

$$\left. + \frac{h^4}{4!} H^{IV}(x, y, o) + \frac{h^6}{6!} H^{VI}(x, y, o) + \cdots \text{etc.}\right]. \tag{12}$$

The term $H(x, y, -h)$ is the continuation upward to a height h and its calculation has been discussed above. We therefore proceed to develop methods of calculating the series in brackets, which we will designate as $F(x, y, h)$ so that

$$H(x, y, h) = 2F(x, y, h) - H(x, y, -h). \tag{13}$$

From Laplace's equation

$$\frac{\partial^2 H}{\partial z^2} = -\left[\frac{\partial^2 H}{\partial x^2} + \frac{\partial^2 H}{\partial y^2}\right]. \tag{14}$$

Since $\partial^2 H/\partial z^2$ is also a potential function it also satisfies Laplace's equation and we have

$$\frac{\partial^4 H}{\partial z^4} = \frac{\partial^4 H}{\partial x^4} + 2\frac{\partial^4 H}{\partial x^2 \partial y^2} + \frac{\partial^4 H}{\partial y^4} = \left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}\right)^2 H \tag{15}$$

and $F(x, y, h)$ can be written in the symbolic form:

$$\begin{aligned} F(x, y, h) = H(x, y, 0) &- \frac{h^2}{2!}\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}\right) H(x, y, 0) \\ &+ \frac{h^4}{4!}\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}\right)^2 H(x, y, 0) \\ &- \frac{h^6}{6!}\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}\right)^3 H(x, y, 0) + \cdots \text{etc.} \end{aligned} \tag{16}$$

In order to make Equation (16) easier to handle without any sacrifice of generality, we transform to polar coordinates and calculate $F(0, 0, h)$. As before we define

$$\overline{H}(r) = \frac{1}{2\pi}\int_0^{2\pi} H(r, \theta)d\theta. \tag{17}$$

It can be shown that continuation downward depends only on the average value of the potential function being continued around circles of radius r. We may therefore write Laplace's equation in the form.

$$\frac{\partial^2 \overline{H}}{\partial z^2} = -\left(\frac{\partial^2 \overline{H}}{\partial r^2} + \frac{1}{r}\frac{\partial \overline{H}}{\partial r}\right) \tag{18}$$

and Equation (16) becomes

$$\begin{aligned} F(0, 0, h) = \Bigg[\overline{H} &- \frac{h^2}{2!}\left(\frac{\partial^2}{\partial r^2} + \frac{1}{r}\frac{\partial}{\partial r}\right)\overline{H} + \frac{h^4}{4!}\left(\frac{\partial^2}{\partial r^2} + \frac{1}{r}\frac{\partial}{\partial r}\right)^2 \overline{H} \\ &- \frac{h^6}{6!}\left(\frac{\partial^2}{\partial r^2} + \frac{1}{r}\frac{\partial}{\partial r}\right)^3 \overline{H} + \cdots \text{etc.}\Bigg]_{r=0|z=0} \end{aligned} \tag{19}$$

where

$$\left(\frac{\partial}{\partial r^2} + \frac{1}{r}\frac{\partial}{\partial r}\right)^i$$

means that the operation is to be applied i times in succession. It can be shown, by an application of Green's Theorem, that $\overline{H}(r)$ is an even function, and it may be written in the form

$$\overline{H}(r) = b_0 + b_2 r^2 + b_4 r^4 + b_6 r^6 + \cdots \text{etc.} \tag{20}$$

If we carry out the operations indicated in Equation (19) we find

$$\left(\frac{\partial^2}{\partial r^2}+\frac{1}{r}\frac{\partial}{\partial r}\right)\overline{H}=4b_2$$

$$\left(\frac{\partial^2}{\partial r^2}+\frac{1}{r}\frac{\partial}{\partial r}\right)^2\overline{H}=64b_4$$

$$\left(\frac{\partial^2}{\partial r^2}+\frac{1}{r}\frac{\partial}{\partial r}\right)^3\overline{H}=2304b_6.$$

Equation (13) for the continuation downward becomes

$$H(0,0,h)=2\left[b_0-2b_2h^2+\frac{8}{3}b_4h^4-\frac{16}{5}b_6h^6+\cdots \text{etc.}\right]-H(0,0,-h). \tag{21}$$

By experience, we find that, in general, the inaccuracies in the observed intensity limit us to the use of the first three terms of the series in Equation (21), but the convergence is rapid enough so that these are fairly adequate for practical purposes.

Therefore

$$H(0,0,h)\cong 2\left[b_0-2b_2h^2+\frac{8}{3}b_4h^4\right]-H(0,0,-h). \tag{22}$$

The values for b_0, b_2, and b_4 are obtained by a least squares solution of the abbreviated form of Equation (20).

$$\overline{H}(r)\cong b_0+b_2r^2+b_4r^4. \tag{23}$$

Using average values of H around circles of radius 0, 1, $\sqrt{2}$, $\sqrt{5}$, $\sqrt{8.5}$, $\sqrt{17}$, $\sqrt{34}$, $\sqrt{58}$, $\sqrt{99}$ we find by the least squares method,

$$\begin{aligned}b_0 = {} & 0.2471\overline{H}(0)-0.2351\overline{H}(1)+0.2234\overline{H}(\sqrt{2})+0.1874\overline{H}(\sqrt{5})\\ & +0.1521\overline{H}(\sqrt{8.5})+0.0717\overline{H}(\sqrt{17})-0.0449\overline{H}(\sqrt{34})\\ & -0.1095\overline{H}(\sqrt{58})+0.0500\overline{H}(\sqrt{99})\end{aligned} \tag{24}$$

$$\begin{aligned}b_2 = {} & -0.0119\overline{H}(0)-0.0105\overline{H}(1)-0.0091\overline{H}(\sqrt{2})-0.0053\overline{H}(\sqrt{5})\\ & -0.0011\overline{H}(\sqrt{8.5})+0.0077\overline{H}(\sqrt{17})+0.0192\overline{H}(\sqrt{34})\\ & +0.0218\overline{H}(\sqrt{58})-0.0108\overline{H}(\sqrt{99})\end{aligned} \tag{25}$$

$$\begin{aligned}b_4 = {} & 0.00010\overline{H}(0)+0.00009\overline{H}(1)+0.00007\overline{H}(\sqrt{2})+0.00004\overline{H}(\sqrt{5})\\ & -0\overline{H}(\sqrt{8.5})-0.00009\overline{H}(\sqrt{17})-0.00020\overline{H}(\sqrt{34})\\ & -0.00020\overline{H}(\sqrt{58})+0.00020\overline{H}(\sqrt{99})\end{aligned} \tag{26}$$

and these, substituted in Equation (22), give coefficients for the circles. By combination with the coefficients for continuation upward $H(0,0,-h)$ given in

Table II, coefficients for continuation downward for $h = 1$ and $h = 2$ are obtained. These are shown in Table III and are for use with the chart of Figure 4. The coefficients for the last circle are adjusted so that the summation of the coefficients is unity. They are used in the manner described earlier for continuation upward. Other methods, some involving the use of weighting factors for the various circles, can be used for the solution of Equation (22). The derivatives in Equation (12) can also be evaluated graphically as will be shown in the next section.

Table III

Coefficients for Continuation Downward

$$H(o,o,h) = C_0\,H(o) + C_1\,H(1) + C_2\,H(\sqrt{2}) + \text{etc.} = \sum_{0}^{9} CH$$

Circle No.	Radius	h = 1 Coeff.	h = 2 Coeff.
0	0	.3969	.4197
1	1	.3026	.3532
2	$\sqrt{2}$	.3356	.5460
3	$\sqrt{5}$	.2749	.4071
4	$\sqrt{8.5}$	.2234	.2668
5	$\sqrt{17}$	.0356	−.0442
6	$\sqrt{34}$	−.2194	−.3762
7	$\sqrt{58}$	−.3413	−.6236
8	$\sqrt{99}$	.1248	.3130
9	$\sqrt{125}$	−.1331	−.1395
	$\sum$	1.0000	1.0000

$$\text{Coefficient for } H(\sqrt{125}) = 1 - \sum_{n=0}^{n=8} C_n$$

Examples of continuation are shown later in this paper.

The development of digital calculating machines which will solve twelve or more simultaneous linear equations will make it a simple matter to calculate coefficients for continuation downward directly from the integral Equation (9).

DERIVATIVE CALCULATIONS

As pointed out above there are two general types of magnetic anomalies present in any magnetic survey. One of these types consists of broad anomalies of considerable magnetic relief, measured usually by hundreds of gamma, while the second type is that composed of sharper anomalies measured usually in tens or units of gamma. From normal considerations of magnetization of basement rocks, it can be shown that the larger anomalies must be caused in large part by variations of magnetization within the magnetic basement, while the smaller features may be due either to smaller magnetization contrasts within the basement or to relief of the basement surface. Obviously there is a great amount of uncertainty, particularly in intermediate types. Whatever the cause of the differentiation, it is essential that methods be made available for the separation of

the smaller anomalies from the more prominent anomalies. One of these methods is continuation downward and was discussed above.

Another method which has been found to be useful for this purpose is that of calculating various derivatives and making contour maps of these derivative values. Smaller anomalies superposed on broad features are identifiable by a change of curvature along any profile, and curvature evaluations depend largely upon the second derivative. For this reason, the second derivative is particularly valuable. In some instances, where used judiciously, the fourth derivative is also valuable.

In the development of analytical continuation, the following expansion was introduced

$$\overline{H}(r) = b_0 + b_2 r^2 + b_4 r^4 \tag{23}$$

and a least squares solution gives the results shown by Equations (25) and (26). When these are substituted in the relationships

$$\frac{\partial^2 H}{\partial z^2} = -4b_2, \quad \text{and} \quad \frac{\partial^4 H}{\partial z^4} = 64 b_4 \tag{23a}$$

for the particular circles used in the analytic continuation chart of Figure 4, sets of coefficients for second and fourth derivative calculations are obtained. However, it has been found unnecessary to carry the computations out so far in the r direction. With sufficient precision for nearly all purposes, a method using circles at radii $r_0=0$; $r_1=1$; $r_2=\sqrt{2}$; $r_3=\sqrt{5}$ and $r_4=\sqrt{9.23}$ has been developed. The value of $\overline{H}(r)$ on the circle of radius r_4 is obtained by taking a weighted average of circles at radii $\sqrt{8}$, $\sqrt{9}$, $\sqrt{10}$, containing 4, 4, and 8 points, respectively. By a least squares solution for Equation (23) and by substitution in the relationships (23a) we obtain

$$\frac{\partial^2 H}{\partial z^2} = 1.156\overline{H}(0) + 0.256\overline{H}(1) - 0.445\overline{H}(\sqrt{2}) - 1.359\overline{H}(\sqrt{5}) + 0.392\overline{H}(\sqrt{9.23}) \tag{27}$$

$$\frac{\partial^4 H}{\partial z^4} = 1.753\overline{H}(0) + 0.170\overline{H}(1) - 1.036\overline{H}(\sqrt{2}) - 2.384\overline{H}(\sqrt{5}) + 1.497\overline{H}(\sqrt{9.23}). \tag{28}$$

These equations give sets of coefficients for the calculation of second and fourth derivatives.

Another method of calculating derivatives is the graphical one. In this method the operations are under close control of the operator, and it is therefore very advantageous when the accuracy of the data is subnormal. It is also very rapid. The method is based on exactly the same fundamentals as those discussed above. By means of an adding machine, the summations of magnetic values

around the circles described above are obtained. Data for the construction of a curve representative of Equation (23) are thus available. However, if we make the substitution $\rho = r^2$ in Equation (23) we have

$$\overline{H}(\rho) = b_0 + b_2\rho + b_4\rho^2 \tag{29}$$

and

$$\frac{\partial \overline{H}}{\partial \rho} = b_2. \tag{30}$$

By plotting the average of the magnetic values around the various circles against the square of the radii as shown in Figure 6, the curve for Equation (29) is available, and the tangent at the origin is the measure of b_2, and $-4b_2 = \partial^2 H/\partial z^2$. By

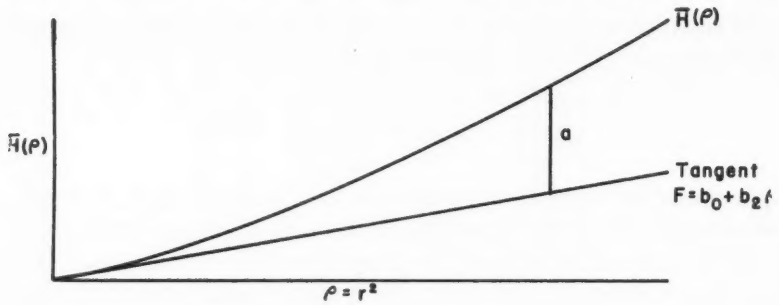


FIG. 6. Graphical computation of derivatives.

proper selection of scales, it is possible to read the derivative directly. The tangent line has the form

$$F = b_0 + b_2\rho. \tag{31}$$

The vertical measurement from any convenient point on the tangent to the curve is therefore equal to $b_4\rho^2$. This vertical distance divided by ρ^2 or r^4 is then proportional to $\partial^4 H/\partial z^4$, since $\partial^4 H/\partial z^4 = 64b_4$, and again a careful selection of scales can permit a direct reading of the fourth derivative.

These methods, being approximations, give results which depend to a considerable extent on the spacings used. We have found it advantageous to use a standardized spacing so that comparisons from area to area are possible. The results are more qualitative than quantitative in value, but these methods have proven to be some of the better tools available for mass production analysis. It is apparent that these methods are applicable without modifications to gravity data.

DERIVATION OF THE ENTIRE FIELD FROM THE VERTICAL INTENSITY

The magnetic potential at any point in the space above the surface of the earth or on this surface can be obtained by multiplying the integral of Equation

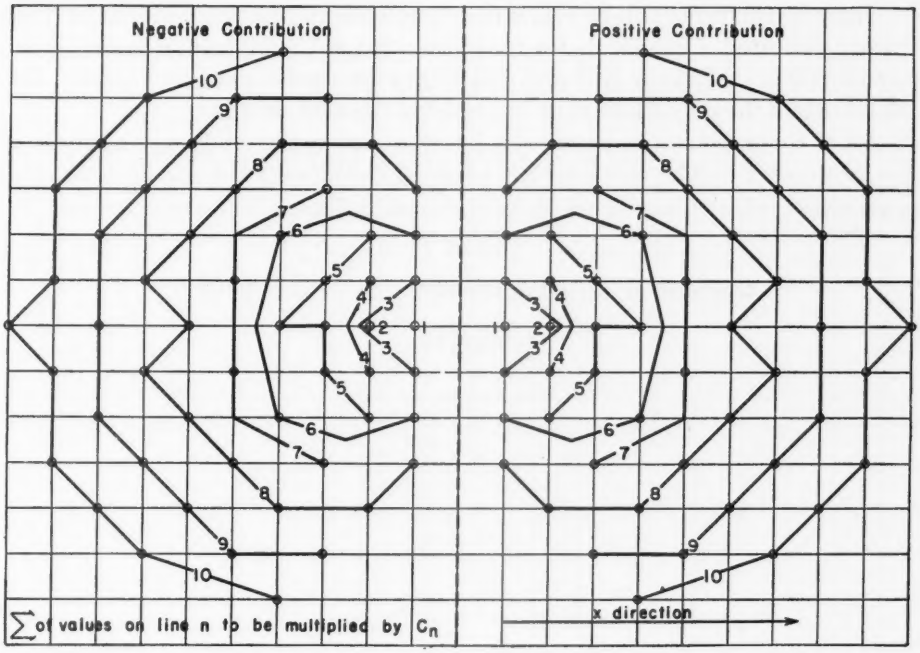


FIG. 7. Grid for calculation of H_z from H_z.

(6) by dz and integrating from $z=-\infty$ to $z=z$. If this operation is carried out we obtain:

$$\phi(x, y, z) = -\frac{1}{2\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\frac{H_z(\alpha, \beta, o)d\alpha d\beta}{[(x-\alpha)^2+(y-\beta)^2+z^2]^{1/2}}. \tag{32}$$

The horizontal components of the field are then given by

$$H_x = -\frac{\partial\phi}{\partial x} = \frac{1}{2\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\frac{(\alpha-x)H_z(\alpha, \beta, o)d\alpha d\beta}{R^3} \tag{33}$$

$$H_y = -\frac{\partial\phi}{\partial y} = \frac{1}{2\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\frac{(\beta-y)H_z(\alpha, \beta, o)d\alpha d\beta}{R^3} \tag{34}$$

where

$$R = [(x-\alpha)^2+(y-\beta)^2+z^2]^{1/2}.$$

The vertical gradient of the vertical intensity can be obtained by taking the derivative of Equation (6) with respect to z. This operation yields:

$$\frac{\partial H_z}{\partial z} = -\frac{1}{2\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\left[\frac{1}{R^3}-\frac{3z^2}{R^5}\right]H_z(\alpha, \beta, o)d\alpha d\beta. \tag{35}$$

These integrals may all be evaluated numerically by methods similar to those already discussed. Coefficients for the calculation of the horizontal intensity are given in Table IV and the grid with which they are used is given by Figure 7. The calculation of the potential will be discussed in the next section.

All of these quantities have been found useful in the study and analysis of specific anomalies. The potential has a special significance because of its relation to structure calculations which we will proceed to discuss in the next section.

Table IV

Calculation of Horizontal Intensity from Vertical Intensity

$$H_x = \frac{1}{2\pi}\sum C_n H_n$$

n	C_n
1	1.5637
2	0.2663
3	0.4400
4	0.1893
5	0.1219
6	0.0951
7	0.0812
8	0.0473
9	0.0315
10	0.0224

THE DIRECT CALCULATION OF STRUCTURE

The direct calculation of basement structure or relief may be approached in several ways. A two-dimensional solution of the problem was given at the beginning of the paper. We can proceed in a similar manner to solve the integral equation relating basement relief to observed intensity. However, in this section we will proceed in a different way.

In Figure 8 let the wavy line represent the basement surface and the horizontal line at $z=h$ represent the average depth to the basement. Further, let $f(x, y)$ be small compared to h and let the polarization be vertical. Under these conditions, it can be shown that the structure of the basement may be replaced by a double layer of strength $I_z f(x, y)$. The magnetic potential of this double layer

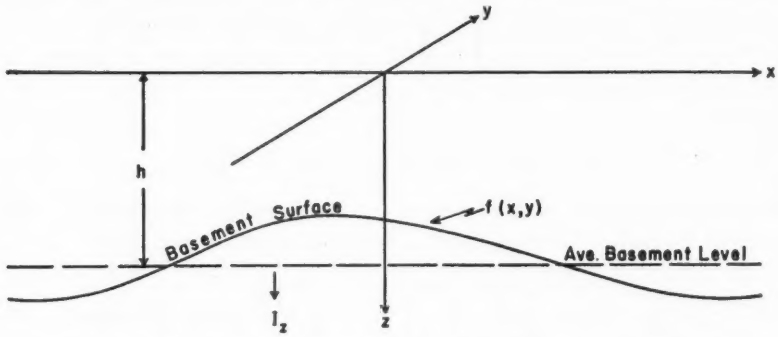


FIG. 8. Method for direct calculation of basement structure or relief.

is given by the equation:

$$\phi(x, y, z) = - I_z \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \frac{f(\alpha, \beta)(h - z)d\alpha d\beta}{[(x - \alpha)^2 + (y - \beta)^2 + (z - h)^2]^{3/2}}. \quad (36)$$

As z approaches h, the integral approaches $2\pi f(x, y)$ and we have

$$\phi(x, y, h) = - 2\pi I_z f(x, y) \quad (37)$$

or

$$f(x, y) = \frac{-1}{2\pi I_z} \phi(x, y, h). \quad (38)$$

Basement relief may thus be calculated either by continuing to the basement level and calculating the potential by the use of Equation (32) using the values

Table V

Coefficients for Calculation of Structure

$$f(o) = \frac{d}{4\pi^2 I_z \times 10^6} \sum C_n H_n$$

Where f is basement relief above mean plane,

d is grid spacing in same units as f.

n	C_n
0	3.670
1	0.985
2	0.910
3	0.427
4	0.382
5	0.267

of H_z at the basement level or by calculating the potential from H_z on the surface where measurements are made and continuing this potential to the basement level.

Before structure calculations can be made, it is necessary to remove the magnetic variations due to polarization changes in the basement rocks. The portion of the field due to these changes can be estimated more easily from the magnetic intensity at or near the basement. Therefore, in general, structure calculations are made using the magnetic intensity at basement level. If one re-

members that $f(x, y)$ is being calculated on the same plane on which the magnetic intensity is known, Equation (32) and (38) combine to give

$$f(x, y) = \frac{1}{4\pi^2 I_z} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \frac{H_z(\alpha, \beta, h)}{[(x-\alpha)^2 + (y-\beta)^2]^{1/2}} d\alpha d\beta. \tag{39}$$

Table V gives a set of coefficients for the evaluation of this integral and the grid with which they are to be used is shown in Figure 9. These coefficients can also be used with proper modification of multiplying factor to calculate the

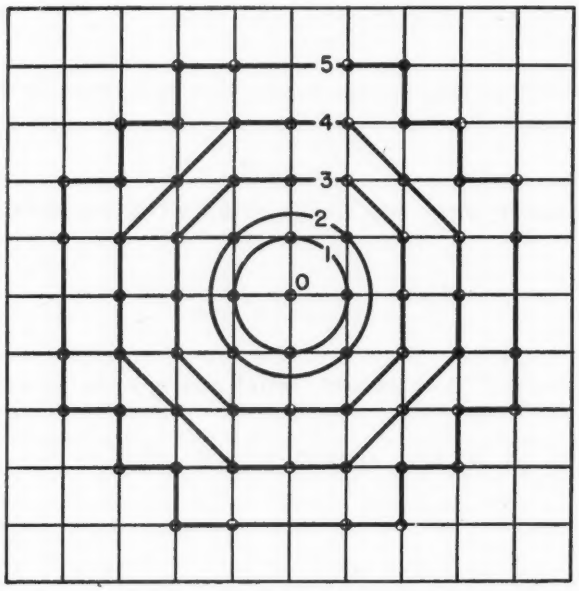


FIG. 9. Grid for calculation of structure using coefficients of Table V.

potential from the vertical intensity on any plane where this intensity is known.

Long, uniform regional slopes contribute practically nothing to the magnetic anomaly field. The structure calculated as outlined above will therefore have to have the regional slope added to it. This regional can be obtained from well information or from magnetic depth estimates. The method of making these estimates is the subject of the next section.

The above theory can be modified to handle cases in which the polarization is not vertical.

ESTIMATION OF DEPTHS TO MAGNETIC BASEMENT

This subject is probably one of the most important phases of magnetic interpretation. The results of a series of depth estimates supply information concerning the thickness of the sedimentary section, and it is therefore possible to

delineate the configuration of a sedimentary basin at low cost and with reasonably high accuracy.

The magnetic potential due to a magnetized body can be written as

$$\phi = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{0}^{z}\left[I_x\frac{\partial}{\partial\alpha} + I_y\frac{\partial}{\partial\beta} + I_z\frac{\partial}{\partial\gamma}\right] \cdot \frac{d\alpha d\beta d\gamma}{\{(x-\alpha)^2 + (y-\beta)^2 + (z-\gamma)^2\}^{1/2}} \tag{40}$$

and

$$H_z = -\frac{\partial\phi}{\partial z}.$$

If it can be assumed that no structure is present (depth constant), then $(z-\gamma)^2 = z^2 = h^2$ for a particular anomaly. If I_x, I_y, and I_z are constants for an anomalous mass, then the integral is a function of the geometric dimensions, except for multiplicative constants, and the solution for depth is unique. However,

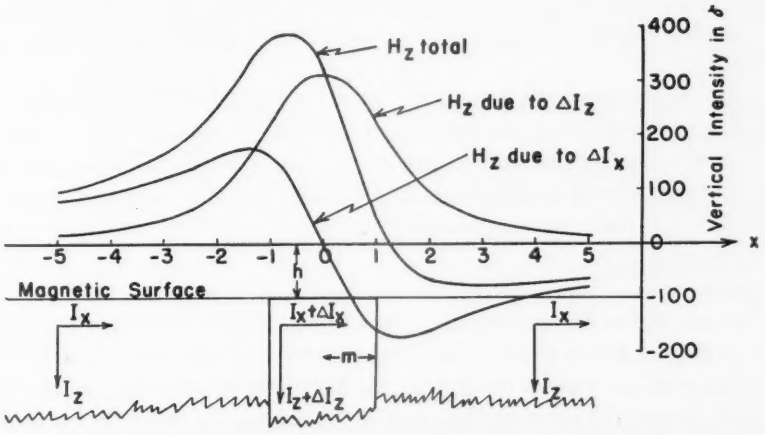


FIG. 10. Method for estimation of depth to magnetic basement.

if I_x, I_y, and I_z are unknown variables in an anomalous mass, it is apparent that there is a complete lack of uniqueness in the solution. A certain degree of uniqueness can be introduced, however, by means of the making of reasonable assumptions. For example, if it be assumed that I_x, I_y, and I_z remain constant over the extent of the geometric mass, and that the magnetization of the surrounding mass is different but uniform, a unique solution can be obtained. In our experience, this form of assumption is applicable in a large number of cases. In Figure 10, the mass is supposed to extend to infinity vertically and in the $\pm y$ directions. The contacts between the masses are vertical. Then

$$H_z = 2\Delta I_z\left[\tan^{-1}\frac{x+m}{h} - \tan^{-1}\frac{x-m}{h}\right] + \Delta I_x \log_e \frac{(x+m)^2+h^2}{(x-m)^2+h^2} + \text{const.} \qquad (41)$$

In many cases, particularly in high latitudes, ΔI_x can be taken as zero. This condition can be recognized readily, since when $\Delta I_x = 0$ the anomaly is symmetrical. In either case, however, the solution for h can be obtained in an indirect manner by a series of successive approximations, in each case recalculating the anomaly to determine the accuracy of the approximation. It will be found that it is necessary to match the observed curve to within 1γ or 2γ before a sufficiently accurate depth is obtained. When $0 \geqq (m/h) \geqq 0.5$ the anomaly is very insensitive to variations in h. Better results are obtainable when $0.5 \geqq (m/h) \geqq 1.1$ and excellent results are obtainable when $(m/h) > 1.1$. Usually when suitable anomalies are available, depths accurate to about $\pm 10\%$ are obtained.

We have found that the assumptions described above are applicable to anomalies of elliptical form, where the major axis of the ellipse is at least three times the magnitude of the minor axis. The profile on which the calculation is made is always taken perpendicular to the major axis and through the apex of the anomaly.

Other forms of anomalies, such as those for right circular cylinders, masses with sloping contacts, etc., are used in a similar manner, but many of these lead to less reliable results, due to the presence of additional unknown parameters. Difficulties encountered in this method of solution are that in many instances the anomaly is disturbed by neighboring masses. Therefore, isolated anomalies should be chosen.

Several short-cut methods for the estimation of depths have been published, mostly for use in the estimation of depths to ore bodies. They are usually based on a set of simple assumptions. For the anomaly derived from a single pole, the depth to the pole is 1.3 times the horizontal distance from the apex of the anomaly to the point where the anomaly has half of its maximum value. For a sphere, the depth to the center is twice this horizontal distance. All of these methods involving half maximum values have a weakness in that it is usually difficult to obtain the value of the anomaly remote from the mass due to the presence of other anomalies, and, therefore, it is not possible to determine the half maximum value with sufficient precision.

A better rule of thumb, for use with the anomaly described by Equation (41) when $\Delta I_x = 0$ is as follows: draw in the maximum slope (at the point of inflexion); draw a line whose slope is one-half this maximum slope; draw two lines parallel to this line, tangent to the anomaly curve. The horizontal distance D between the points of tangency is approximately equal to $1.6h$. Actually, when $m/h = 0$, $D = 1.2h$ and when $m/h = \infty$, $D = 2.0h$. For intermediate values of m/h, $D = 1.6h$

gives a fair estimate. This method can be applied to magnetic contour maps. On the flanks of each elongated anomaly, a band of fairly uniformly spaced contours will be found. The width of this uniform band is a measure of D. Great care must be used in the selection of anomalies for these calculations. For quick interpretations, this technique has been adequate.

Direct methods of depth estimation also can be made. These methods are based on analytic continuation. They are limited largely by inaccuracies in the observed data and, of course, by the lack of uniqueness that applies to all potential function data. The continuation of the vertical intensity to any depth gives to within a constant multiplier a distribution of magnetic material which will account for the observed field. As the continuation is carried deeper and deeper, a point is reached at which the simple, sharp distributions are inadequate to reproduce the observed field, and the continued field begins to oscillate violently. This oscillation is indicative that the maximum depth has been passed at which a simple distribution of magnetic material will produce the observed field. Broad anomalies, which probably originate from within the basement complex, can be continued further than the sharper ones. As in the case of the indirect method of making depth estimations, we have found that a proper choice of anomalies leads to surprisingly accurate depth calculations.

One way of systematizing depth calculations is by the use of a technique called the "error curve" method.

If continuation is carried downward to a depth h and then back up again by the methods discussed above, fairly accurate results are obtained on theoretical data such as the arc tangent until the depth of burial is approached. Beyond this depth the error increases rapidly. To apply the method the following procedure is followed.

Let H_a be the recalculated surface intensity from continuation downward at depth h.

Then

$$H_a = \sum C_n \overline{H}(b_n h). \tag{42}$$

where $\overline{H}(r)$ is the average value of the observed magnetic intensity around a circle of radius r, and b_n is a constant.

By a combination of methods described earlier, the values of Table VI have been obtained.

On a reasonably strong anomaly, make an approximate depth estimate by one of the short-cut methods. The accuracy of this estimate need not be better than about 50%. Select the point of greatest curvature on the anomaly, by inspection. No great accuracy is required here. Using this point as a center, describe circles of radius $b_n h$ where h is the approximate depth estimate. Multiply the average values around these circles by the appropriate value of C_n, and sum the results. Repeat the process, replacing h by $h/2$, $3h/2$, and $2h$ in order. A curve is then plotted, E against h, as in Figure 11. The particular curve in Figure 11 was that

Table VI

Coefficients for the Calculation of Error in Continuation for Use in Estimation of Depths

$$E = H_0 - H_a = H_0 - \sum C_n \bar{H}(b_n h)$$

b_n	C_n
0.1	0.3001
0.3	0.5102
0.5	0.2622
0.7	0.0311
0.9	-0.0378
1.1	-0.0348
1.3	-0.0190
1.5	-0.0087
1.7	-0.0035
1.9	-0.0011
2.25	0.0000
2.75	0.0007
3.25	0.0003
3.75	0.0003

obtained over a theoretical polarization contrast anomaly, in which case the true value of h is known. The sharp bend point would be selected as the depth of burial in a practical solution.

All of these methods must be used with great care, and isolated anomalies should be chosen, since in every case the effect of neighboring anomalies is detrimental to accuracy.

Some other useful tools have been developed. Where a magnetization contact lies at one depth of burial or farther from the center of an anomaly, the second

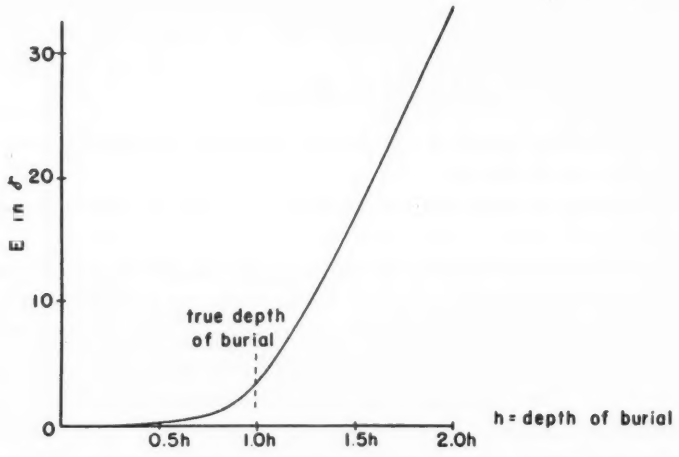


FIG. 11. Error curve for an abrupt polarization change obtained by means of coefficients of Table VI.

derivative in the vertical direction is approximately equal to zero at the contact. This gives a measure of one of the parameters, and is therefore useful in making first approximations to the dimensions of a disturbing mass. First and second derivatives can be taken graphically in the horizontal direction by measurements of slopes, and these are often useful in depth estimate work, since in some instances the horizontal derivatives of functions to be matched are more amenable to solution than the functions themselves.

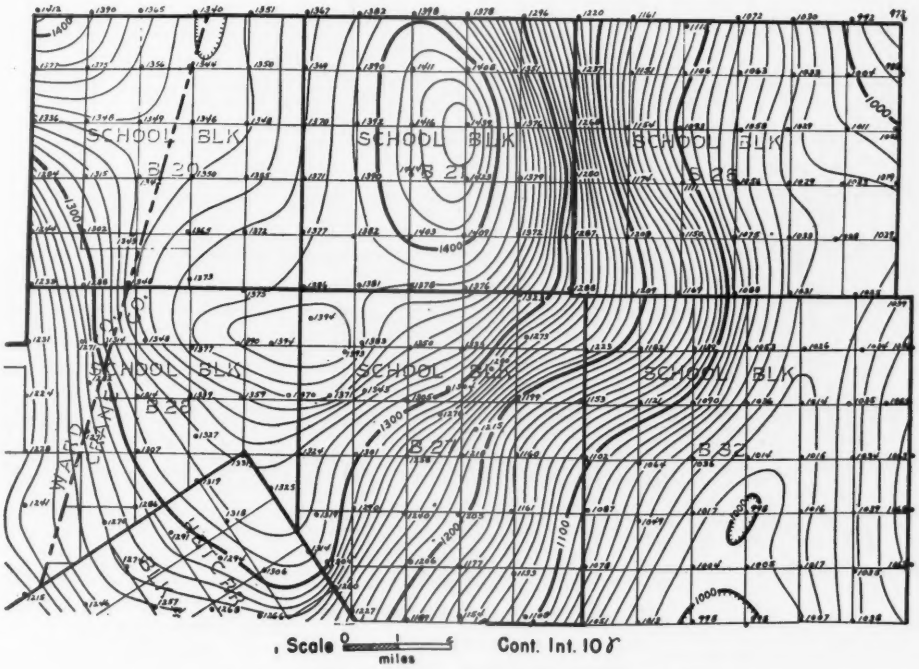


FIG. 12. Observed vertical magnetic intensity portion of Crane and Ward Counties, Texas.

In order to illustrate the practical applications of the theory developed above, a series of six maps is presented. Figure 12 is a map presenting the observed magnetic intensity in a portion of Ward and Crane Counties, Texas, covering the general Sand Hills Area. The observations were made on the corners of a mile grid, and they have been corrected for the normal northward increase of the earth's field.

Figure 13 shows the second vertical derivatives of magnetic intensity. Since these derivatives are a measure of the changes of magnetic gradients, the derivative anomalies should coincide with the nonlinear parts of the observed intensity map. The wells shown on this map and others to follow are those which reached the Ellenburger Limestone, in Lower Ordovician. In almost every instance, it is noticeable that the Ellenburger production is on the flank of one of these anom-

alies. The Sand Hills Field is the outstanding example. The whole anomaly correlates closely with the outline of Permian production and the Ellenburger production is on the north flank. This may mean that the Ellenburger Lime is thin or absent over the top of this anomaly. The same applies quite well to the other anomalies. This second derivative map alone would have been quite sufficient to localize these structures and to guide the seismograph with a high degree of precision.

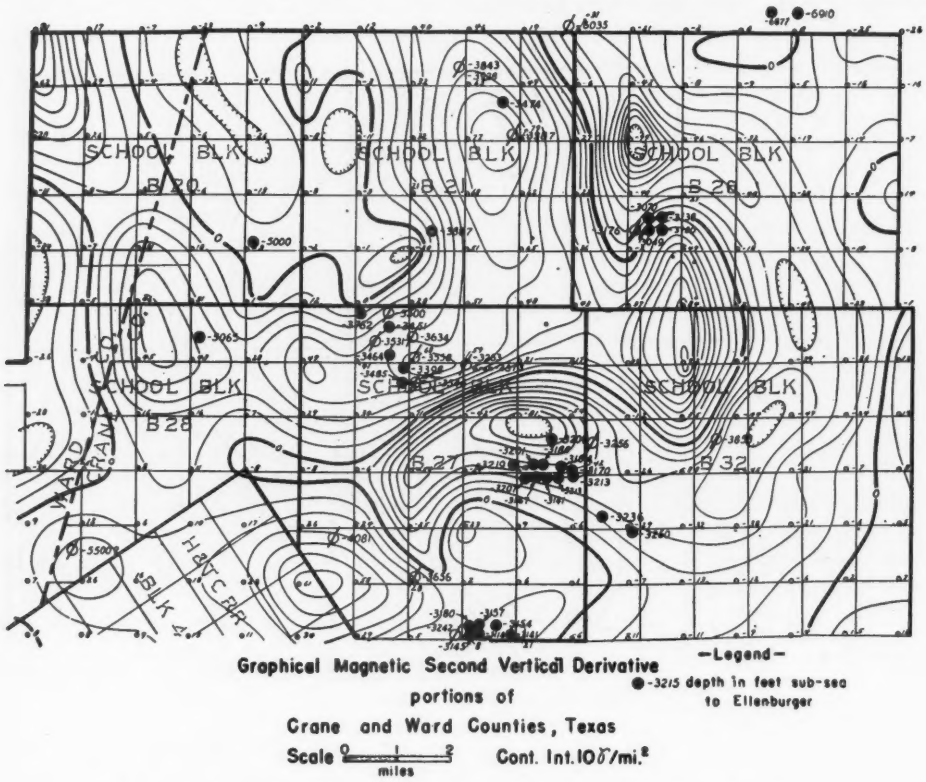


FIG. 13. Graphical magnetic second vertical derivative portions of Crane and Ward Counties, Texas.

Figure 14 is the fourth derivative map. Fourth derivatives tend to oscillate rather widely unless excellent data are available, and they should be used with considerable discretion. In this area, however, the data are good and the fourth derivative calculations are justified. Observe the increased detail on the anomalies and the fault indications, particularly on the east flank of the Sand Hills structure and on the east flank of the McKnight Field. The flanking lows are merely parts of the derivative anomalies caused by the fault. Note that the production on the "Sand Hills Ordovician Field" at the center of the map is definitely on the west flank of the feature. Faulting is suggested on the north and south flanks. The production on the anomaly at the bottom of the map is on the west flank of the feature and faulting is indicated. Derivative maps are normally used in a qualita-

tive manner. If it is deemed advisable or necessary to calculate the structural relief, another technique is necessary.

Figure 15 shows the vertical magnetic intensity on the basement surface, calculated from the observed intensity on the earth's surface. This is the "Analytic Continuation Downward." The appearance of this map is quite similar to that of the derivative maps. However, these values are in units of intensity, and the

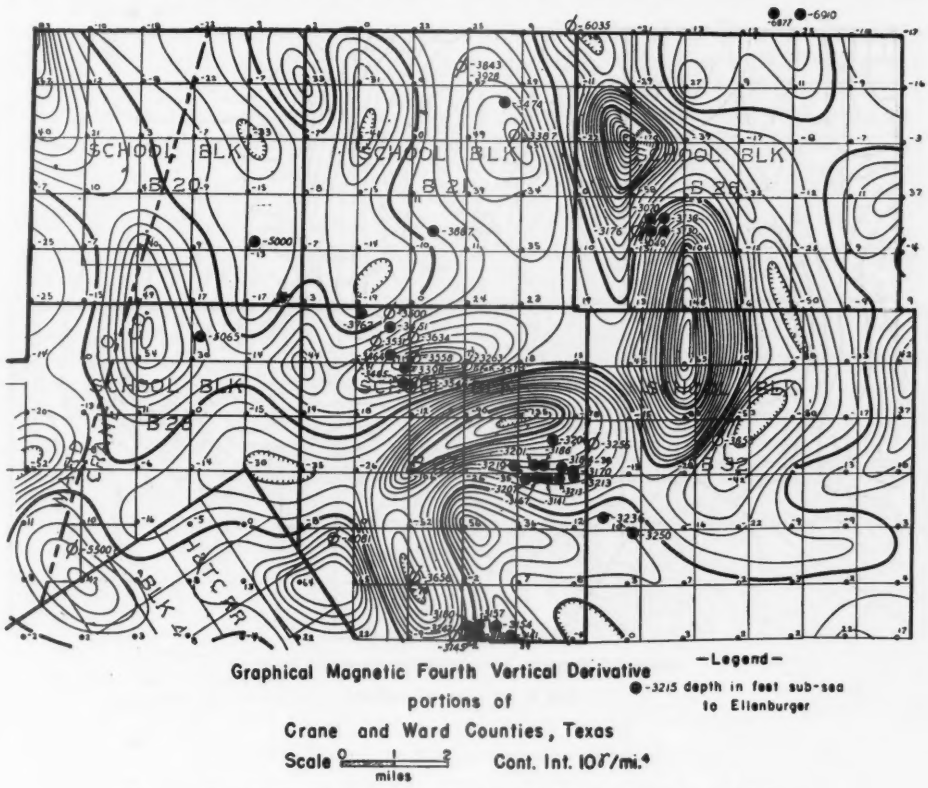


FIG. 14. Graphical magnetic fourth vertical derivative portions of Crane and Ward Counties, Texas.

structural relief can be derived from these values. The details of the anomalies are not quite so apparent as they are on the derivative maps, due to the presence of a broad regional effect. As mentioned earlier, part of the magnetic relief is derived from the more highly magnetized rocks underlying the Basin Platform.

The light contours on the map of Figure 16 show the magnetic relief which, in our judgment, is caused by the more highly magnetized rocks underlying the platform. It is a matter of interpretation and not of calculation, of course, and it is probable that other equally valid assumptions could be made. The sharp anomalies are obtained by subtracting this broad regional from the values shown on the previous map, and the anomalies represent the magnetic intensity at the average basement level caused by structure deformations.

In Figure 17 the values and contours represent the calculated structure. Since broad regional structures give only a few gamma relief, and since uniform slopes give no magnetic relief, this picture presents only the sharp undulations of the basement. Since the spacing of control points is not much smaller than the depth to the basement rocks, there is considerable flattening over what we conceive the actual structure to be. The true picture would probably show much steeper

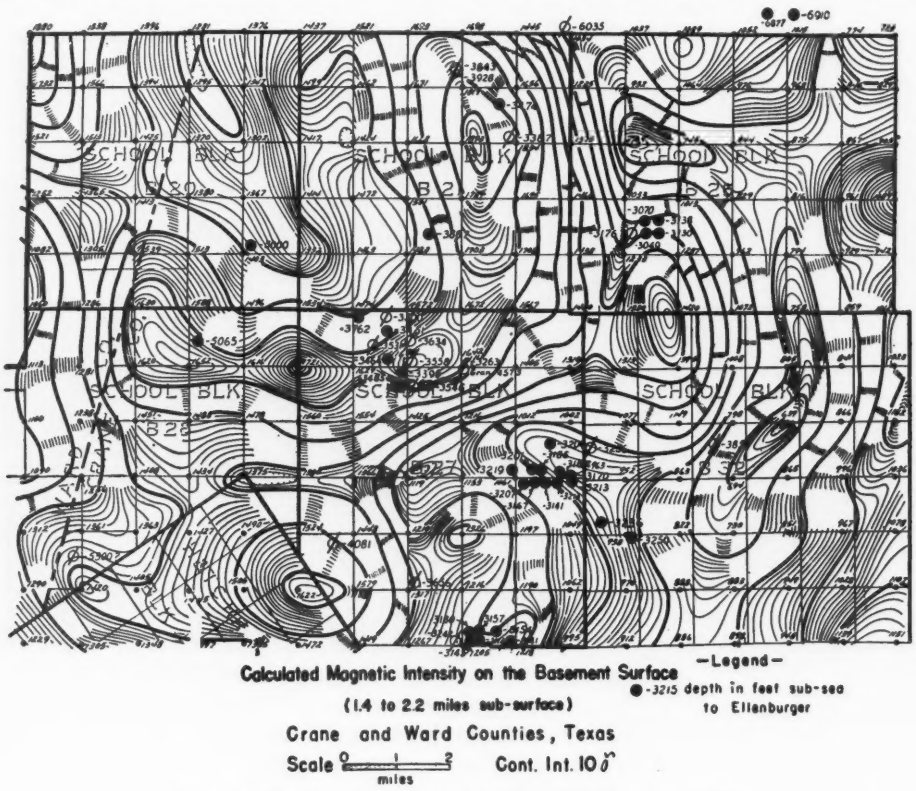


FIG. 15. Calculated magnetic intensity on the basement surface (1.4 to 2.2 miles sub-surface).

slopes or faults in many places, such as on the east flank of the Sand Hills Field and on the east flank of the structure in Block 21. The polarization used in making the structure calculations was about 0.001 c.g.s. units.

In Figure 18 the regional contours were derived largely from well information and represent that part of the relief which the magnetic method cannot show, since it involves gentler, more uniform slopes. The contour interval is 500 feet. By the addition of this regional to the values of the previous map, we obtain the picture shown by the sharper contouring. This is the final phase of the routine interpretation and represents the calculated relief of the basement. The datum is in feet subsea and the contour interval is 100 feet. The picture could be improved by making the flanks steeper, and by sketching in faults where indicated by the derivative and continuation maps.

Our seismograph work in this area shows excellent correlation with the magnetic results, and it has been found possible to use the magnetic information as an aid in determining which of two possible seismograph interpretations should be used. Here and elsewhere in this vicinity, the seismograph and magnetic fault indications correspond almost exactly.

We have shown no examples of depth estimates in this paper. They are, however, one of the most valuable uses of magnetic data and would in themselves justify the surveying of new areas even if no other information could be derived from the survey. A careful selection of features on which to make depth estimates

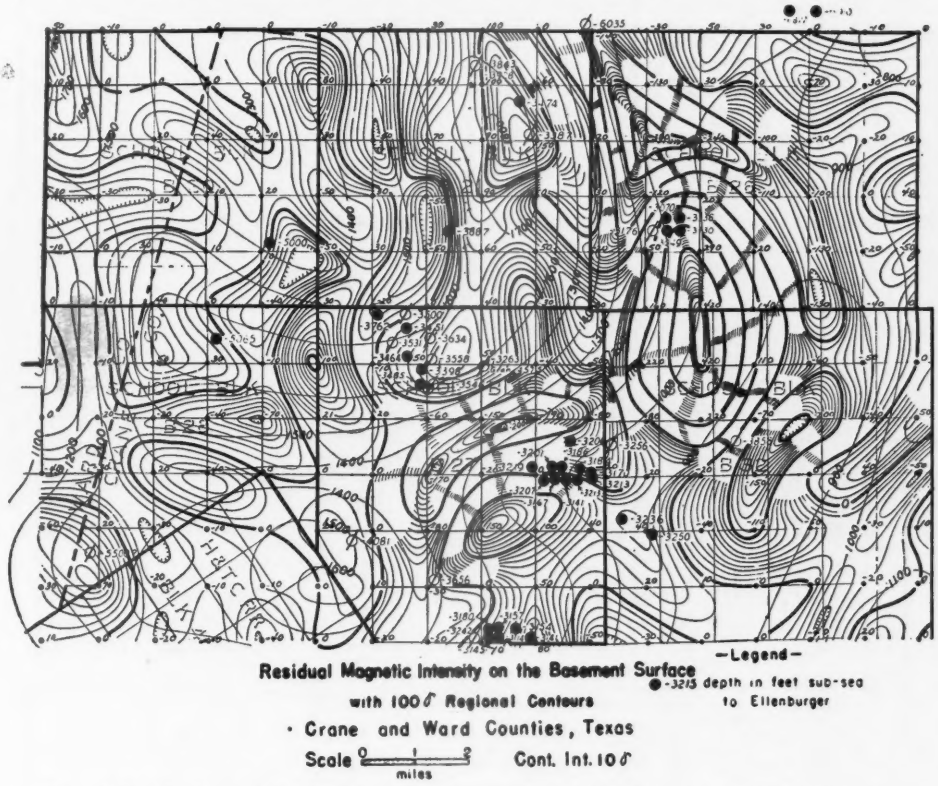


FIG. 16. Residual magnetic intensity on the basement surface with 100 r regional contours—Crane and Ward Counties, Texas.

enables one to outline basins, and to map on a large scale basis with surprising accuracy the thickness of the sedimentary column and to outline major uplifts in basins. Over the past 12 or 15 years some 90% of our depth estimates are probably accurate to better than ±20% and some 75% are probably accurate to within ±10%. The word "probably" is used above because only a few of our estimates have been checked by wells which reached the igneous basement. The accuracy of the others can only be inferred from other information.

If over an area the anomalies are small compared to the total field of the earth so that the magnetic vector changes its direction but little, airborne data in which

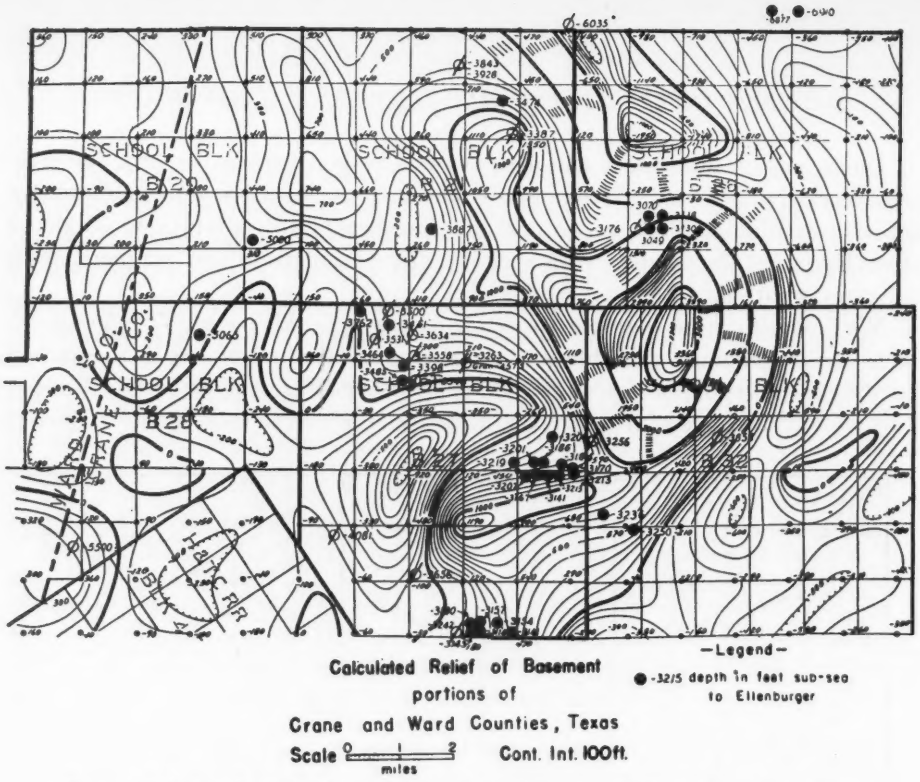


FIG. 17. Calculated relief of basement portions of Crane and Ward Counties, Texas.

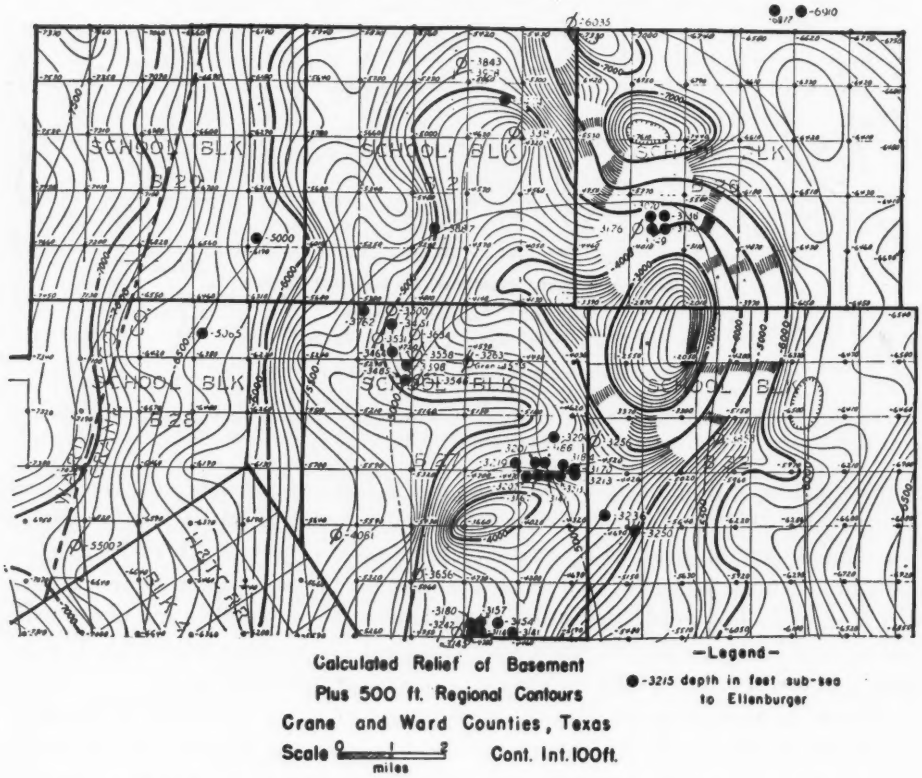


FIG. 18. Calculated relief of basement plus 500 ft. regional contours—Crane and Ward Counties, Texas.

the total field is measured can be considered to approximate a potential function. This implies that the coefficients for continuation upward, for continuation downward, and the techniques for calculating derivatives can be applied without modification to these types of data. The theory covering potential and structure calculations must be appropriately modified before being applied.

In order that this paper may be of maximum value to geophysicists interested in the interpretation of data depending on potential fields, there is given below a rather complete bibliography on the subject.

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ON THE STRATIFICATION OF THE EARTH'S CRUST ACCORDING TO SEISMIC STUDIES OF A LARGE EXPLOSION AND OF EARTHQUAKES*

L. MINTROP**

ABSTRACT

The analysis of the seismograms of an explosion of 4,000 tons (about 10 million pounds) of munitions piled up in tunnels 50 feet below the surface of the rocky island of Heligoland in the North Sea near Hamburg, Germany, and of a great number of natural earthquakes, especially the disastrous shock at Messina (Italy) led to the discovery of a number of formations unknown heretofore down to a depth of several hundred kilometers. At depths from 110 to 118 km a plastic layer occurs which seems to represent a belt around the globe. At a depth of 183 km the melting point of a material with very high wave-velocity is reached. These findings are in accordance with the determination of the depth of Isostatic Surface by Hayford and Helmert (both in 1909) from deflections of the vertical and/or from gravity anomalies (113 and 118 km, respectively). Qualitatively, the results are also in accordance with the assumption of Gutenberg and Richter, based on the measurement of the amplitudes of the first recorded waves from numerous earthquakes with different epicenter distances and with different depths, that at a depth of 80 to 100 km the melting point of the material has been reached.

It has been much easier for the seismologist to determine the core of the earth at a depth of about 2,900 km than any interface between two formations with different wave-velocities within the crust of the earth. But, in 1910, A. M. Mohorovičič,[1] by studying the seismograms and time-distance curves to the earthquake of Agram of October 8, 1909, found for the first time a very pronounced break in the time-distance curve as shown in Figure 1. Assuming the depth of the focus of the earthquake to be about 25 km, Mohorovičič determined a depth of the interface of about 50 km. There, the velocity of the first recorded (longitudinal) wave jumps from 5.7 km/sec up to 7.7 km/sec. Mohorovičič has, also, calculated the travel-time of a wave reflected from this interface. St. Mohorovičič, the son of A. M. Mohorovičič, in 1916 determined the depth of the interface to be nearly 60 km. He found two more discontinuities in the upperlying layers and some indications of interfaces at depths of 120 km. and about 400 km.

The "Mohorovičič Layer" with a wave velocity of around 8 km/sec (Pn wave), has been checked by many authors within the United States as well as in Europe and other continents. The depth of the focus of the earthquake of Agram was overestimated by the Mohorovičičs and the depth of the interface is less than 50–60 km, averaging about 30 km with regional variations depending on the geological situation in each region. The layer is to be considered as Peridotite.

For a number of years it has been assumed by the seismologist that the wave velocity within the Peridotite formation increases continuously down to a very

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** Professor Dr. Ludger Mintrop, Essen-Werden, Barkhoven Allee 36, Germany, British Zone.

[1] A. M. Mohorovičič, "Das Beben vom 8-10-1909," *Jahrbuch des Meteorologischen Observatorium Zagreb*, Agram *9* (1910), Teil 4, 1.

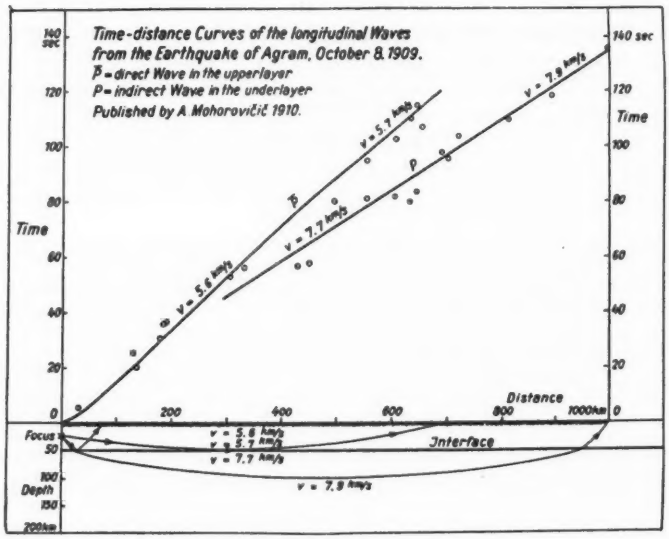

FIG. 1. Detection of an interface within the earth's crust by A. M. Mohorovičič in 1910.

great depth. Gutenberg[2] of Pasadena recently gave a review of the results obtained by different authors (see Fig. 2). They all assume a more or less steady increase of the first recorded (longitudinal) wave, down to a depth of at least 220 km. But, from studies of the amplitudes of the first waves from nearby shocks with different epicenter distances and different depths, Gutenberg, cooperating

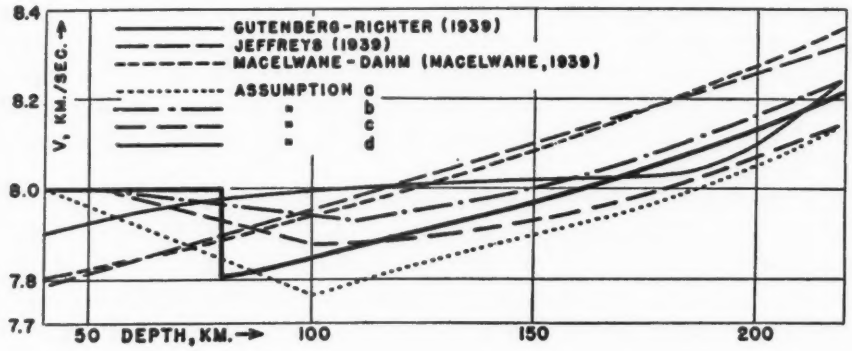

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FIG. 2. Determination and/or assumption of the velocity of the longitudinal wave beneath the Mohorovičič interface by different authors.

[2] B. Gutenberg, "On the Layer of Relatively Low Value Velocity at a Depth of About 80 Kilometers," *Bulletin of the Seismological Society of America*, Vol. 38, No. 2, April, 1948.

with Richter, also from Pasadena, came to the conclusion that at a depth of about 80 to 100 km the melting point of the Peridotite layer had been reached, the wave velocity decreasing suddenly from 8.0 to 7.8 km/sec as seen in Figure 2. Below this depth the wave velocity increases nearly at the same rate as Jeffreys, Macelwane and Dahm had assumed.

The explosion on the rocky island of Heligoland in the North Sea, near Hamburg on April 18, 1947, where 4,000 tons (about 10 million pounds) of munitions piled up in tunnels about 50 feet below the surface, were detonated in one big shot offered a very rare chance to obtain more information on the stratification

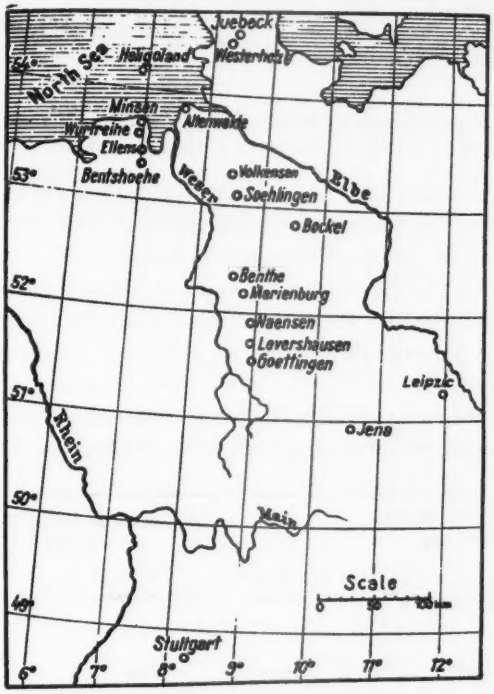

FIG. 3. Map of the western part of Germany with the locations of Heligoland and of seismic stations.

of the earth's crust in case proper seismic observations could be made. With the support of the British Military Authorities, the German State Geological Survey and the Geophysical Institute of the University of Goettingen all arrangements necessary could be made for obtaining good seismograms. In addition to the seismographs of the observatories at Goettingen, Jena, Leipzig and Stuttgart about 15 field seismographs were set up, most of them in a north-south profile up to a distance of 310 km (nearly 200 miles) from the shotpoint. The greatest distance in which records were taken was 608 km (Stuttgart, see the map in Fig.

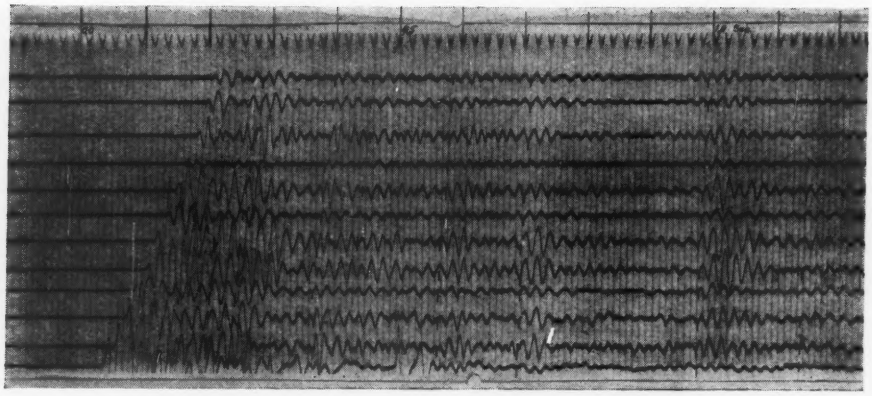

FIG. 4. Multiple reflection record from oil prospecting in Northwest Germany south of Heligoland, taken in 1943 by Seismos, Hanover. Charge 2 pounds of dynamite.

3). The moment of the blast was transmitted by radio waves to all stations. The results of these observations have been reported by J. Bartels, H. Reich and G. A. Schulze[3] at a meeting of the Royal Society in London, November 20, 1947. The Peridotite layer with a velocity of 8.1 km/sec for the first recorded (longitudinal) wave had been determined by these investigators in the profile from Heligoland to Goettingen at an average depth of 27 ± 3 km but no deeper discontinuities were reported.

The author who takes no credit at all for the organization and the accomplishment of the large scale observations had been invited by Professor Dr. Julius

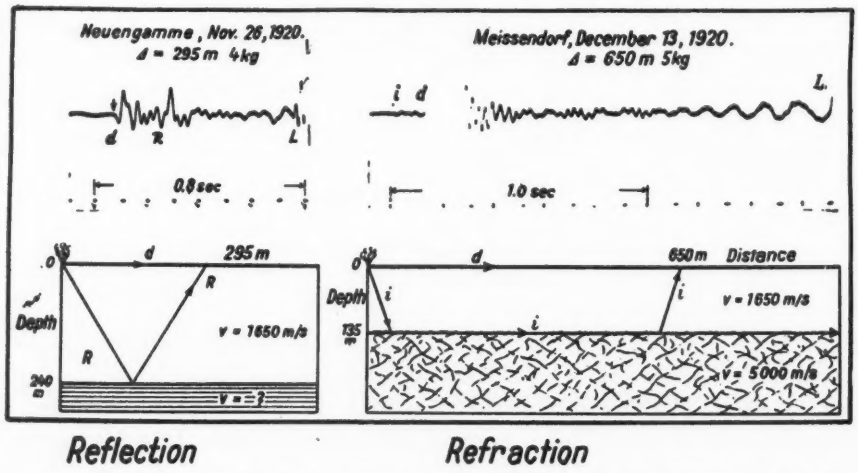

FIG. 5. Refraction and single reflection records taken by L. Mintrop in 1920 within the salt-dome district of Northwest Germany south of Heligoland.

[3] G. S. Schulze, "Seismische Ergebnisse der Heligoland-Sprengung," *Die Naturwissenschaften*, *34* (1947), Heft 9, Seite 288.

Bartels, Director of the Geophysical Institute at Goettingen to be present when the ground and air waves from the mammoth explosion arrived. The sound through the air could be heard as thunder from lightning 200 miles away and the first glance at the perfect seismograms was very impressive. Later on Dr. Bartels invited the author to analyze the seismograms. Only mechanical seismographs were used in this experiment, and no multiple reflection outfit which had been developed in the United States to a very high perfection. Such outfits were available in Germany as the record in Figure 4 shows, but no use of them had been made in the experiments of Heligoland. Therefore the author had to try to solve the problem with the same methods which he had started in 1920 after the discovery of refracted[4] and reflected waves on the seismograms of artificial earthquakes (see Fig. 5). As shown in the refraction seismogram the amplitude of the

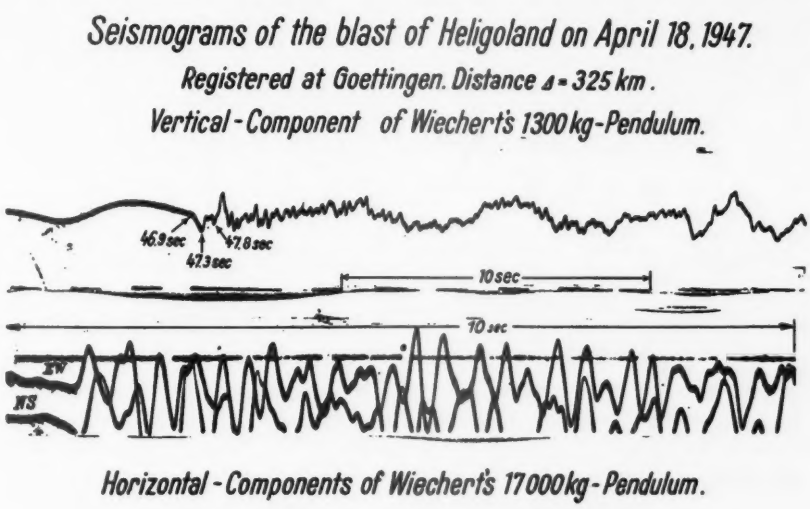

FIG. 6. Three component seismograms of the blast on Heligoland, recorded at Goettingen at a distance of 325 km.

refracted wave is very small on account of the great difference in the wave velocities within the soft overlayer and the crystalline underlying formation (salt). We have to keep this in mind when we are looking at some seismograms of the blast of Heligoland and of natural earthquakes.

Figure 6 shows the seismograms taken at Goettingen at a distance of 325 km from the shotpoint. The upper curve represents the vertical component, the lower two are the horizontal components of Wiechert's astatic pendulums. Usually the instruments recorded the seismic waves on smoked paper, but, for the Heligoland experiment they had been provided with a photographic recording

[4] W. C. Salm, "Ueber die Energie der Mintrop-Welle," *Beitraege zur angewandten Geophysik*, 4 (1934), 364–372.

device, the magnification of the incoming waves being about 50,000. The seismographs were well damped.

Forty-six and nine tenths seconds after the moment of the blast the first wave arrived, followed 0.4 and 0.9 second later by two other waves. The records are 30 feet long and contain numerous impeti.

Figure 7 shows the vertical seismogram of a field station set up at a distance of 66 km from the shotpoint. The first wave with a small amplitude arrived 14.06 seconds after the explosion and within one second five more events occurred before the very large waves came in. They show many interferences partly

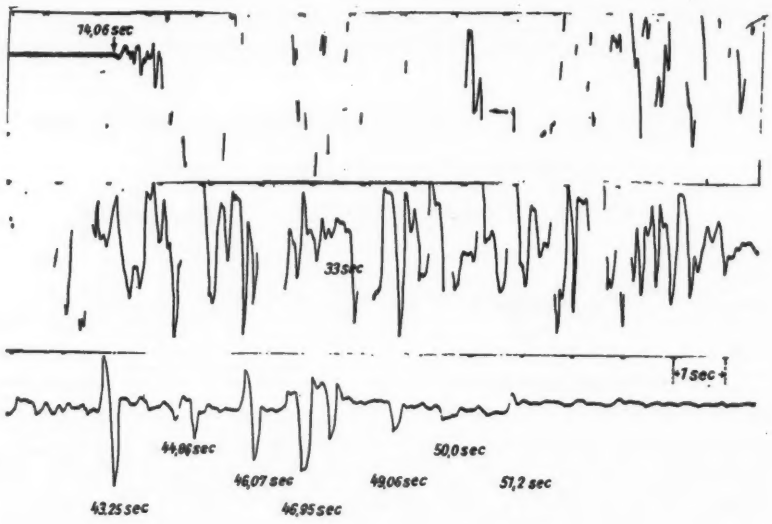

FIG. 7. Vertical component seismogram of the blast on Heligoland, recorded at a distance of 66 km.

caused by reflections from shallow and deep interfaces. Between 43.25 and 51.2 seconds after the moment of the shot 7 "after-shocks" occur with very pronounced impeti but alternate change in appearance. The author at once believed that these impeti would be reflections from very deep layers of very different elasticity and density, but not having the benefit of the records of a multiple-reflection outfit it was very difficult to decide the question. As seismograms of other nearby field stations showed the same kind of after-shocks the author is quite sure that we have to deal with reflections.

Wiechert in his early experiments with long-range shots 23 years ago picked up a wave with the travel-time of 42 seconds which he thought could be a reflec-

tion. As the distance from the shotpoint was only 18 km the average velocity is 428 meters/second, much too low for a layer wave in the rocky region in which the experiment of Wiechert had been carried out. Krumbach in 1926 calculated

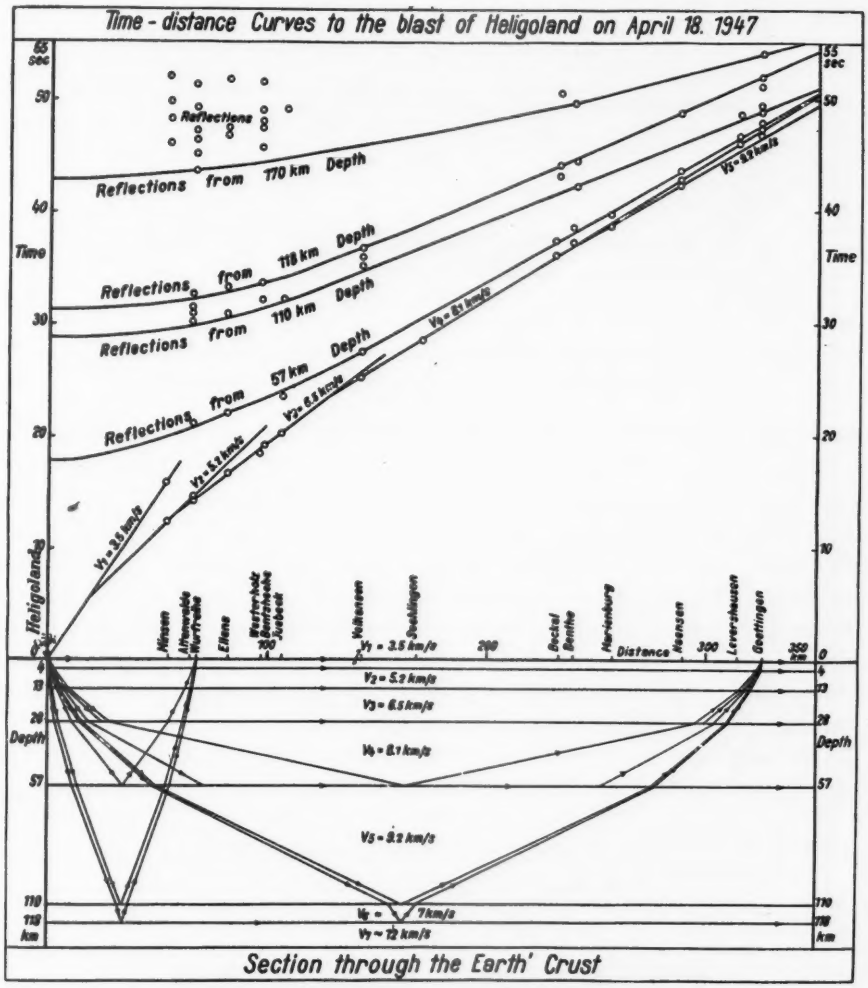

FIG. 8. Time-distance curves of the first recorded waves from the blast on Heligoland and section through the earth's crust.

the depth of the reflecting horizon as 146 km but he did not know the average velocity of the wave which now has been determined by the author.

The analysis of the seismograms recorded on 19 stations resulted in the time-distance curves of refracted and reflected waves as shown in Figure 8. The velocity of 3.5 km/sec for the longitudinal wave in the sediments represents an

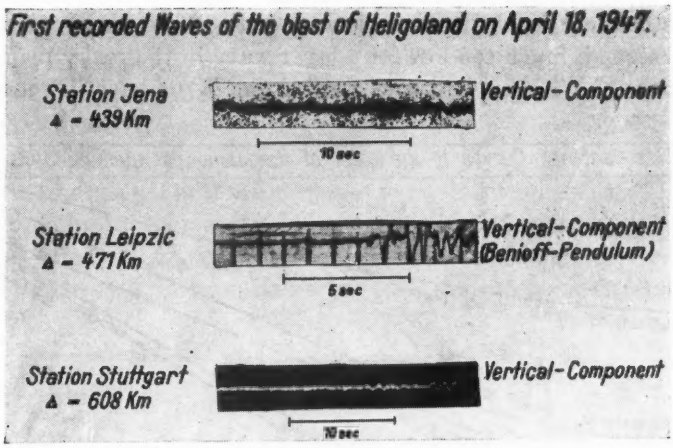

FIG. 9. Vertical component of the first recorded waves of the blast on Heligoland, registered at Jena, Leipzig and Stuttgart at distances of 438, 471 and 608 km.

average value, but the velocities in the underlying formations have been determined by a number of time-distance observations. The velocities of 5.2 and 6.5 km/sec indicate the presence of a granitic and a basaltic layer whereas the velocity of 8.1 km/sec corresponds with the velocity of the Pn wave in Peridotite (Mohorovičič layer). Beneath this, a heretofore unknown layer with the wave velocity of 9.2 km/sec, occurs the Pn+1 wave which perhaps is Pyroxenite.

Reflections from shallower interfaces have also been observed, but the time-distance curves for the reflected waves from the surfaces of the granitic, basaltic and peridotite layers have not been drawn in Figure 8 because these formations had already been determined by many authors.

Reflections from the Pn+1 interface give a very clear travel-time curve and the calculated depth of the reflecting horizon is in accordance with the depth of 57

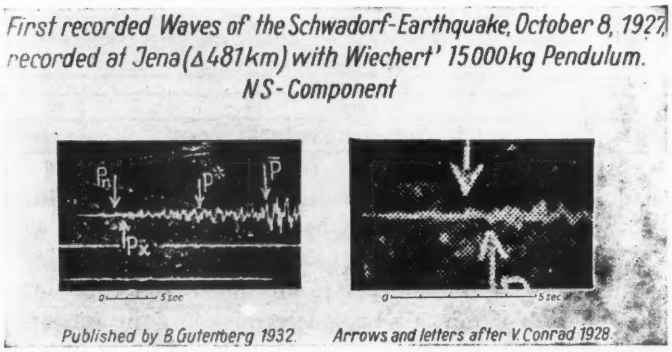

FIG. 10. North-south component of the first recorded waves from the Schwadorf earthquake of October 8, 1927, recorded at Jena at a distance of 481 km.

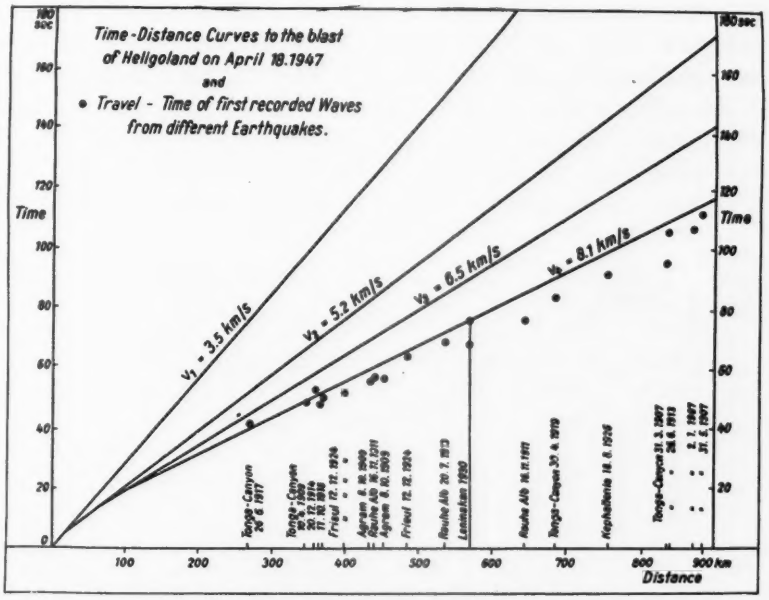
Time-Distance Curves to the blast of Heligoland on April 18.1947
and
• Travel - Time of first recorded Waves from different Earthquakes.
Time
Distance
V_1 = 3.5 km/s
V_2 = 5.2 km/s
V_3 = 6.5 km/s
V_4 = 8.1 km/s

FIG. 11. Time-distance curves of the first recorded waves from the blast of Heligoland and travel-times of the first recorded waves from different earthquakes.

km determined by refractions. No reflections have been observed between 57 and 110 km depth where a group of reflections appear, indicating a disturbed zone 110–118 km deep. The next reflections came from an interface the depth of which has been calculated as 170 km and a further reflecting horizon at a depth of 183 km. Beneath this again a group of reflections appears indicating another dis-

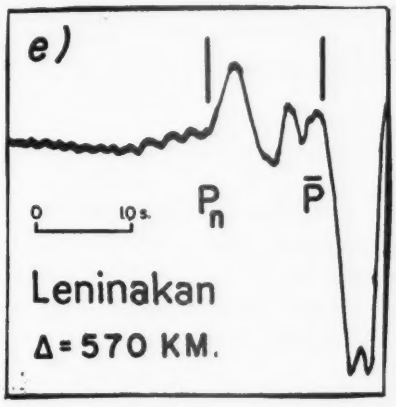

FIG. 12. Seismogram of the first recorded waves from the earthquake of Leninakan at a distance of 570 km, published by Gutenberg.

turbed zone. But before these depth calculations could be made it was necessary to determine the wave velocities within the upper disturbed zone as well as within the solid layer underlying this zone. This has been done by observing refracted waves from these layers at greater distances from the shotpoint. The records of the seismological stations at Jena, Leipzig and Stuttgart (see Fig. 9) at epicenter distances of 439, 471 and 608 km. show clear impeti of the Pn wave but there are only very uncertain indications of prior events. This may be due to

FIG. 13. Map of Europe showing the epicenter of the Messina earthquake of December 28, 1908 and other European earthquakes including that of Schwadorf, near Vienna, on October 8, 1927.

the fact that the seismographs at these stations were not so well adjusted to the experiment of Heligoland as the instruments at Goettingen and the field stations were. Nevertheless, there appear some indications of impeti before the Pn wave so that nobody could say that there are not indications at all and the question could not be decided.

Fortunately, there is a record available from a natural earthquake at Schwadorf, near Vienna (see the map in Fig. 13) which had been recorded at Jena with the same instrument as the blast of Heligoland and practically the same epicenter

distance (see Fig. 10). This record had been published by Conrad in 1928 and by Gutenberg[5] in 1932. Both authors have marked the Pn-wave by an arrow, but as it is seen very clearly there appear waves with very small amplitudes several seconds before the arrival of the Pn-wave. Now we are sure that the very small indications of faster waves on the seismograms in Figure 9 have a real significance.

Stimulated by these facts, the author has studied a great number of records from natural earthquakes, all of them showing events up to 14 seconds before the arrival of the Pn-wave as to be seen in the time-distance curves in Figure 11.

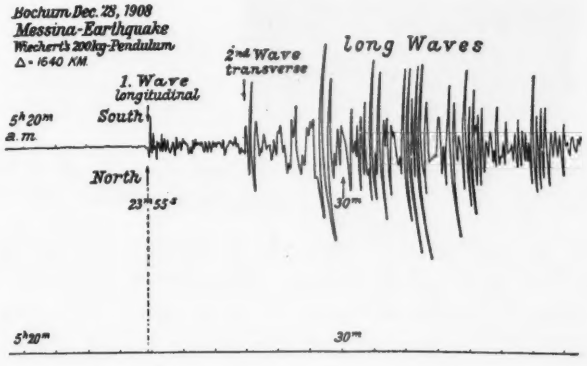

FIG. 14. South-north-component seismogram from the Messina earthquake of December 28, 1908, recorded by the author at Bochum at a distance of 1,640 km.

The record of the earthquake at Leninakan taken at an epicenter distance of 570 km and published by Gutenberg[6] shows forerunners 9 sec. ahead of the Pn-wave, but with comparatively small amplitude (see Fig. 12). What is the reason for such small amplitude? If it would be the damping influence of the disturbed zone at the depth of 110 km then it would be a question of energy to push the wave through this zone and to generate a wave within the solid formation beneath the disturbed zone.

In order to decide this question the author turned to the records of the disastrous earthquake of Messina, Italy, which occurred on December 28, 1908 destroying the entire city and killing a hundred thousand people. The energy released by this tremendous shock is estimated to have been about ten thousand times larger than that by the explosion on Heligoland. Figure 13 shows a map of Europe with the epicenters of the Messina earthquake and other European earthquakes. In Figure 14 the record of the south-north horizontal component at the earthquake observatory at Bochum which had just been erected by the author has been reproduced. The seismogram shows the longitudinal and transverse

[5] B. Gutenberg, "Aufzeichnung des Bebens von Schwadorf bei Wien am 8. October 1927, in Jena," *Handbuch der Geophysik*, Band IV (1932).

[6] B. Gutenberg, "Seismological Evidence for Roots of Mountains," *Bulletin of the Geological Society of America*, 54 (April 1, 1943), 473–498.

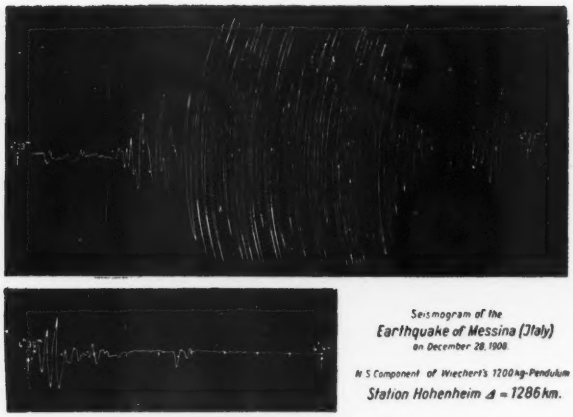
Seismogram of the
Earthquake of Messina (Italy)
on December 28, 1908.
N S Component of Wiechert's 1200 kg-Pendulum
Station Hohenheim Δ = 1286 km.

FIG. 15. South-north-component seismogram from the Messina earthquake of December 28, 1908, recorded at Hohenheim near Stuttgart at a distance of 1,286 km.

waves as well as the later strong waves which caused a movement of the ground of one-quarter of an inch, 1,640 km away from the focus of the Messina earthquake. Before what had been thought at that time would be the first impetus, very small waves appear which had been considered as some unrest of the ground.

Very, very small waves are also to be seen at the beginning of the record of the seismograph at Hohenheim near Stuttgart (see Fig. 15) at a distance of 1,286 km from Messina.

The enlarged part of the records in Figure 16 shows these first waves more clearly, also on the records taken at Munich and on Heligoland at distances of

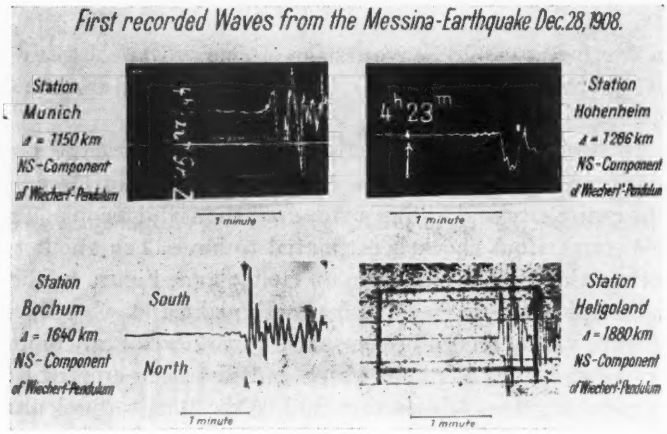
First recorded Waves from the Messina-Earthquake Dec. 28, 1908.
Station Munich Δ = 1150 km NS-Component of Wiechert-Pendulum
4h 23m
Station Hohenheim Δ = 1286 km NS-Component of Wiechert-Pendulum
1 minute
1 minute
Station Bochum Δ = 1640 km NS-Component of Wiechert-Pendulum
South
North
Station Heligoland Δ = 1880 km NS-Component of Wiechert-Pendulum
1 minute
1 minute

FIG. 16. Enlarged south-north-component seismograms of the first recorded waves from the Messina earthquake of December 28, 1908, recorded at Munich, Hohenheim, Bochum and on Heligoland at distances of 1,150, 1,286, 1,640 and 1,880 km.

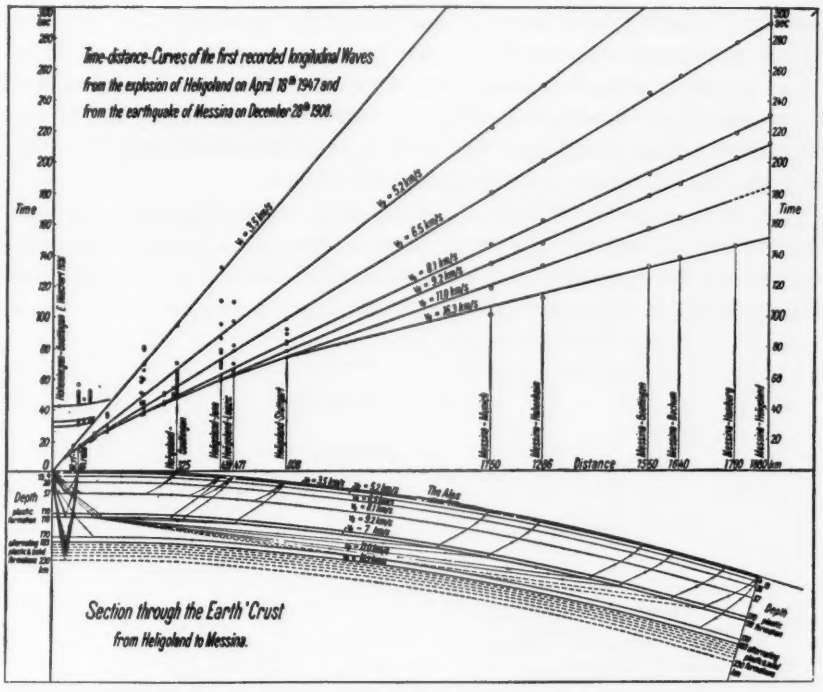
Time-distance-Curves of the first recorded longitudinal Waves
from the explosion of Heligoland on April 18th 1947 and
from the earthquake of Messina on December 28th 1908.
Time
Distance
Section through the Earth 'Crust
from Heligoland to Messina.

FIG. 17. Combined time-distance curves of the first recorded waves from the blast on Heligoland on April 18, 1947 and from the earthquake of Messina on December 28, 1908 and a section through the earth's crust.

1,150 and 1,880 km, respectively. It might be mentioned here that the island of Heligoland carried a seismological station at that time. A very small first wave is to be seen on the seismogram from this station too.

Figure 17 shows the combined time-distance curves to the blast of Heligoland and to the Messina earthquake and also a cross-section through the earth's crust derived from these curves. The 8.1 km/sec-formation has been used as the leading layer (Pn). All in all, there occur eight very well defined interfaces at depths of 4, 13, 28, 57, 110, 118, 170 and 183 km, the velocities of the longitudinal waves within the different layers being 3.5, 5.2, 6.5, 8.1 (Pn), 9.2 (Pn+1), circa 7 (Pn+2), 11.0 (Pn+3), and 16.3 (Pn+4) km/sec. Laboratory experiments have shown that the velocities of 11.0 and 16.5 km/sec occur in corundum and in diamonds, respectively. The velocity of 7 km/sec within the disturbed zone is just an estimation on the assumption that they indicate a plastic layer, the melting point for the solid formation with a wave velocity of 9.2 km/sec being reached at the depth of 110 km. When crystalline material melts the velocity of the longitudinal wave falls off up to 50% and more of its value within the solid state the rate being about 30% in silicates.

Beneath the lowest solid layer with a wave velocity of 16.3 km/sec a number of reflections occur and the average velocity of the longitudinal wave in this region may be about 9 km/sec which would be very close in accordance with the results obtained by seismologists who have determined the depth-velocity curves for the interior of the earth neglecting more or less the earth's crust and assuming that the wave velocity increases gradually with depth.

As the stations at Goettingen, Jena, Leipzig and Stuttgart and several field stations had registered all three components, the author could draw the time-distance curves for the transverse waves also. The velocities within the different formations were: ca. 2 km/sec (average value) for the sediments, 2.9 km/sec for

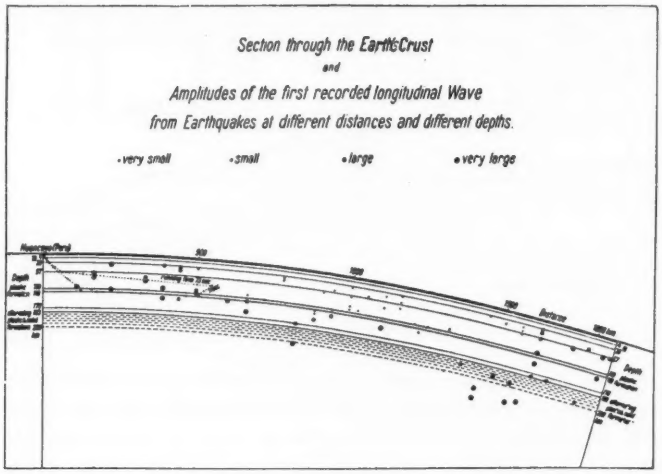

FIG. 18. Section through the earth's crust and amplitudes of the first recorded waves from different earthquakes at different depths, observed by Gutenberg and Richter.

the granitic layer, 3.6 km/sec for the basaltic formation, 4.5 km/sec within Peridotite (Pn) layer, 5.0 km/sec for the Pn+1 formation, 6.2 km/sec within the Pn+3 layer, and 8.8 km/sec for the Pn+4 formation, the velocities within the first disturbed (plastic) zone remaining unknown whereas the velocity of the transverse wave at the depth of the second broken (plastic) zone has been determined by seismologists to be about 5 km/sec.*

The finding of a plastic layer by the author at a depth from 110 to 118 km has been compared with the results of very detailed investigations made by Gutenberg[7] and Richter of Pasadena. These authors have measured the amplitudes of the first recorded waves on a large number of seismograms from natural

* Poisson's ratio for the different layers increases with depth irregularity from 0.27 to 0.37.

[7] B. Gutenberg, "Variations in Physical Properties Within the Earth's Crustal Layers," *American Journal of Science, 243A*, R. A. Daly Volume 1945.

earthquakes, with different epicenter distances, and with different depths of the foci, using especially records of the seismological observatory at Huancayo, Peru. At distances from about 500 km up to about 1,600 km the first impeti are very small. From these observations Gutenberg arrived at the conclusion that at a depth of 80 to 100 km the melting point of the material must have been reached. When the results of all of his observations are plotted in the cross sestion through the earth's crust (Fig. 17) they fit in very well as shown in Figure 18.

The explanation by the author of the very small amplitudes is that the first recorded wave had to penetrate the plastic (disturbed) layer at the depth from 110 to 118 km and then to generate a high-velocity-wave in the underlying solid layer, losing by this procedure most of its energy. At distances greater than 1,600 km the small amplitudes have not been observed; probably the first impeti had too little energy to be recorded.

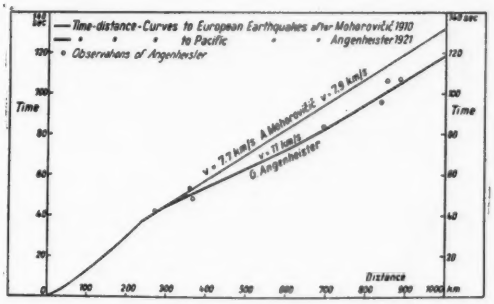

FIG. 19. Time-distance curves of the first recorded waves from the earthquake at Agram on the European Continent and from an earthquake beneath the Pacific Ocean as plotted by A. M. Mohorovičić and G. Angenheister, respectively.

In 1921 Angenheister[8] published the results of the analysis of the seismograms from very strong earthquakes on the Tonga Trough east of Australia. At epicenter distances between 400 and 800 km the amplitudes of the first recorded waves were very small but the velocity of these waves was very high (11 km/sec), 3 km/sec greater than had been found by Mohorovičić on the European Continent (see Fig. 19). Pointing to the fact that such a high velocity never had been observed anywhere else Angenheister drew the conclusion that the layers below the waters of the Pacific Ocean should have a much higher elasticity and would be entirely different from the formations within the outer crust of the continents. The geologists know of such differences, but the observations made by Angenheister do not prove this difference because the same wave-velocity of 11 km/sec has now been observed on the European Continent too and the depth of the layer with the high wave-velocity of 11 km/sec is about the same under the Pacific

[8] G. Angenheister, "Beobachtungen an pazifischen Beben," *Nachrichten der Gesellschaft der Wissenschaften zu Goettingen, Mathematisch-Physikalische Klasse* (1921).

Ocean as it is under the surface of the European Continent. Unfortunately, Angenheister had not calculated the depth of the 11 km/sec layer.

From the results of the experiment of Heligoland combined with the results of the study of the seismograms of natural earthquakes by the author and from the observations made by Gutenberg, Richter and Angenheister the author concludes that the plastic layer at the depth from 110 to 118 km represents a belt around the globe (see Fig. 20). The depth of this layer corresponds with the depth of the isostatic surface calculated from deflections of the vertical and/or from gravity anomalies by Hayford[9] (113 km) and Helmert[10] (118 ± 22 km), but this surface seems to be related to a plastic layer of a thickness of about 8 km.

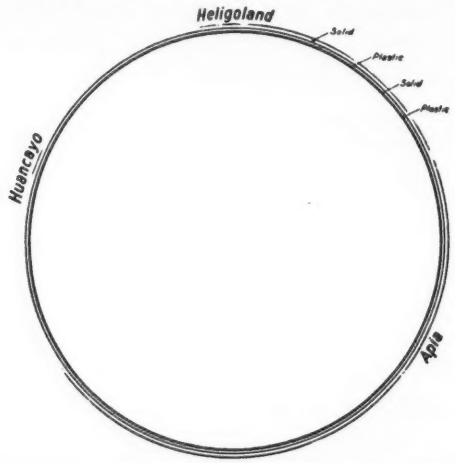

FIG. 20. Solid and plastic formations within the earth's crust.

In the opinion of the author it will be of great importance to determine the anomalies of the depth of this plastic layer, especially in mountain and large basement regions. The amount of dynamite necessary for obtaining good records from such great depths, especially of reflections, will not be unreasonable inasmuch as the records of the waves generated by the blast on Heligoland are taken by relatively insensitive mechanical seismographs. The use of the very sensitive electrical seismometers and multiple trace recording devices will not only be much more economical, but also will facilitate the determination and the correlation of reflecting layers.[11]

[9] J. F. Hayford, "The Figure of the Earth and Isostasy from Measurements in the United States Coast and Geodetic Survey, Washington" (1909).

[10] F. R. Helmert, "Die Tiefe der Ausgleichsflaeche bei der Pratt'schen Hypothese fuer das Gleichgewicht der Erdkruste und der Verlauf der Schwerestoerung vom Innern der Kontinente und Ozeane nach den Kuesten," *Sitzungsberichte der Preussischen Akademie der Wissenschaften*, Vol. XLVIII (1909).

[11] M. A. Tuve, R. W. Goranson, J. W. Greig, W. J. Rooney, J. B. Doak, and J. L. England, "Studies of Deep Crustal Layers by Explosive Shots," *Transactions American Geophysical Union, 29*. No. 6 (1948), 772.

CORRELATION POSSIBILITIES IN THE SACRAMENTO VALLEY*

K. S. COHICK†

Several years ago while doing routine seismic shooting in a portion of the Sacramento Valley near the town of Elk Grove, several prominent reflection bands were noticed recurring on many of the profiles. Five selected profiles are shown in discussing reflection correlation over this small, comparatively ideal area. Figure 1 shows the general location of the profiles which range from 2 to 8 miles apart. Figure 2 shows three records whose location can be seen by referring

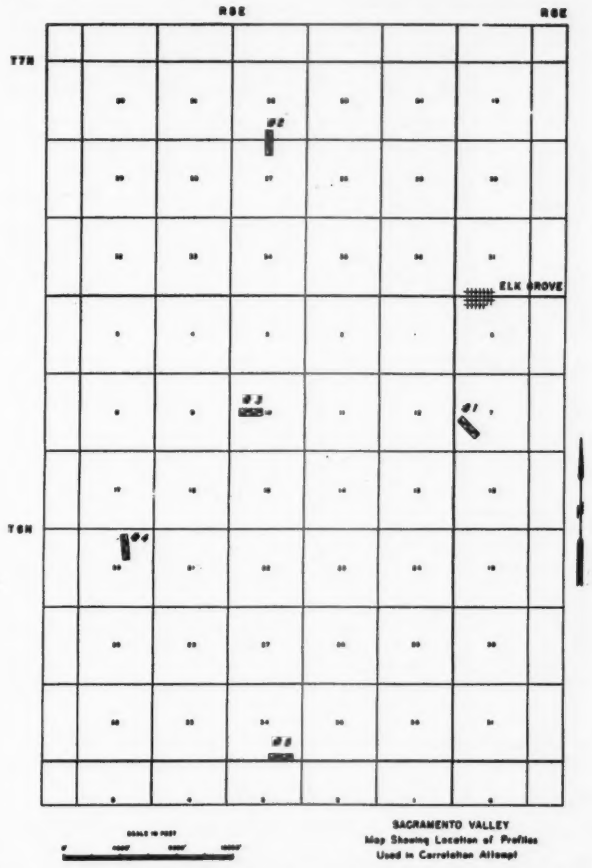

FIG. 1. General location of profiles, ranging from 2 to 8 miles apart.

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† Shell Oil Company, Inc., Sacramento, California.

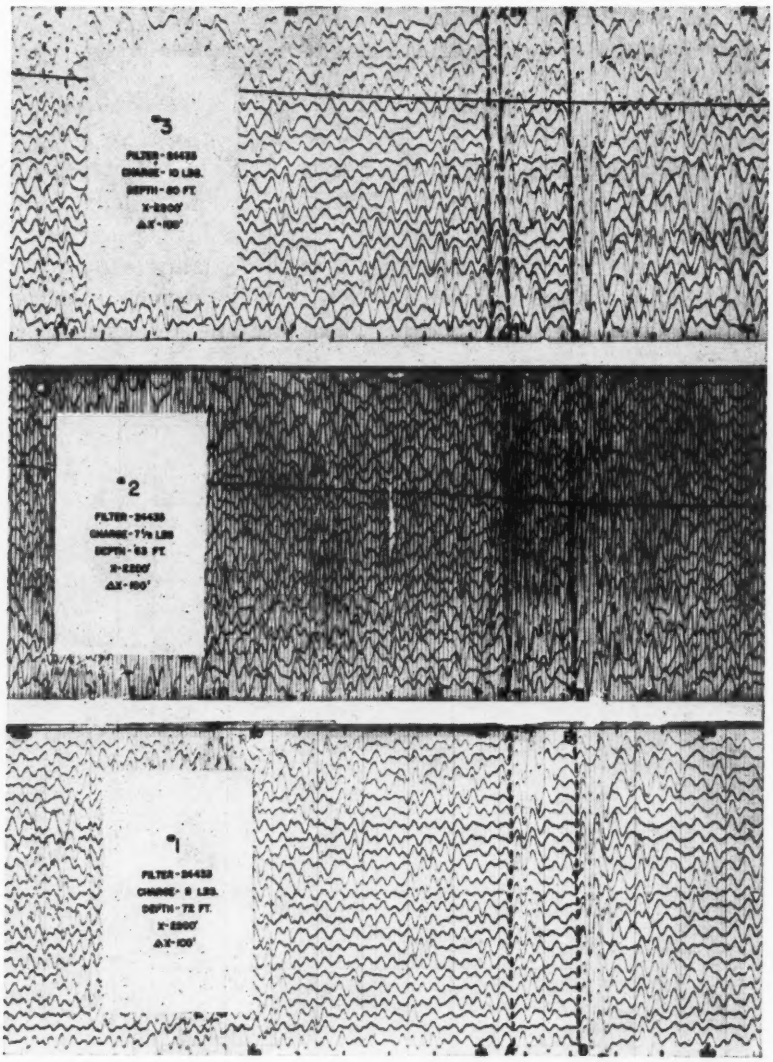

FIG. 2. Three correlation records whose location can be found on Figure 1.

to Figure 1. Records 1, 2, and 3 were correlated as shown by events A and B. When the B events are correlated as shown, there is some evidence that in going from record 2 to 3 the A event could correlate with A'. However, when the records are studied more carefully, it appears that the interval between reflection bands thickens and that events A and B should be correlated as marked on all three records. This correlation was independently substantiated by connecting continuous profile lines. It would appear then that between these three records, jump correlation might be done with a fair degree of accuracy.

Figure 3 shows two attempts to extend this correlation beyond the immediate area of the first three records. Going from record 3 to 4 approximately 2 miles in a southwestward direction, there appear to be several possible ways of correlating. Event *B* on 3 may be *B′* on 4, then *A′* on 3 would be *A* on 4. Another possibility is that event *A* on 3 is *A* on 4 but then event *B*, from the interval between reflection bands, would appear to correlate with something between *B* and *B′* as marked on 4. The correlation which appears to be correct, as determined by con-

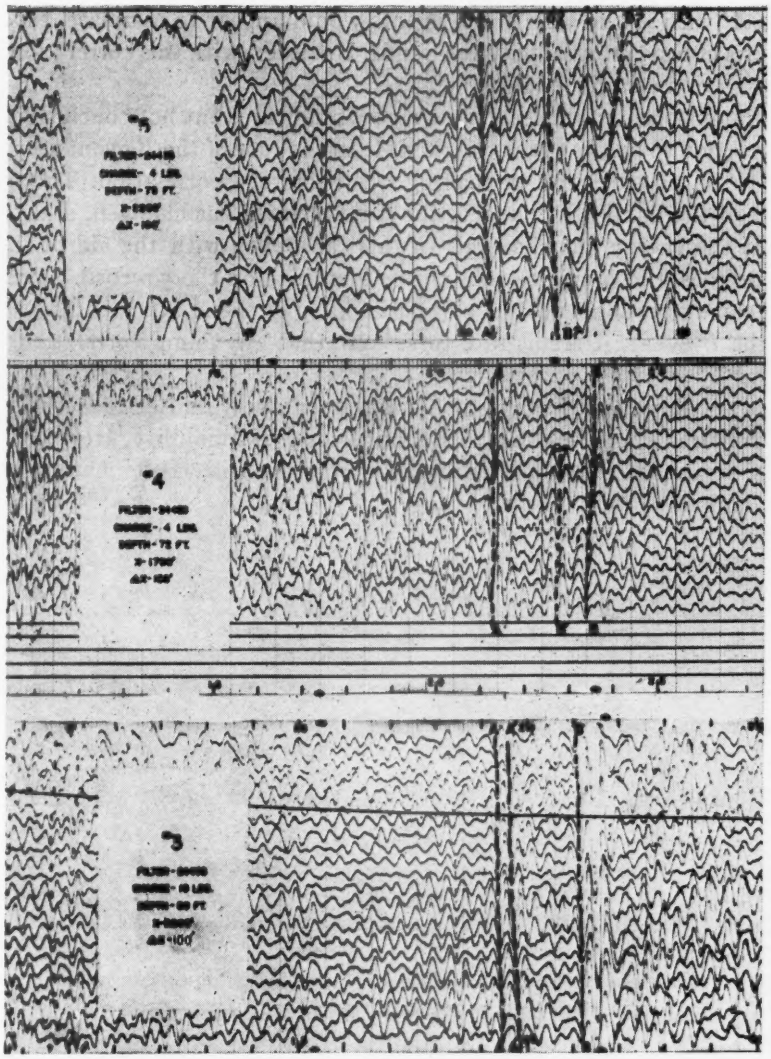

FIG. 3. Two attempts to extend the correlations beyond the immediate area shown on Figure 2.

tinuous profiling, is that events *A* and *B* on 3 correlate with events *A* and *B* on 4. The dissimilarity of the *B* events on the two records makes it questionable whether these events would have been *jump* correlated correctly. From these considerations it seems fair to assume that in trying to jump correlate to the westward of this immediate area, we would have no more than a 50 percent chance of being correct.

Jump correlating southward to profile 5 from either 3 or 4 would probably result in correlating the *A* event as shown. In going from 3 to 5 we could possibly correlate *A'* with *A* and then the *B* events would appear to correlate, especially on the basis of time interval between bands. However, with this correlation many other correlation criteria would be violated.

Continuous profiles between these records indicate, but not conclusively, the best correlation to be the events marked *A*. In the case of the *B* event on 5, there appears to be no sure way of making a satisfactory correlation. The general character of the band has changed, the time interval has changed, and the frequency of the energy has changed. In this case, even with the aid of the continuous profiles, the *B* event could not be identified on the 5 record. Since there was still some question as to the correct identity of the *A* event and no correlation of the *B* event, it seems safe to assume that any jump correlation to the southward is extremely uncertain.

By way of summary then it appears that over a very limited rather ideal area jump correlation could be done with a fair degree of reliability. However, when attempts were made to extend this area slightly, the correlation method became too unreliable to permit is general usage.

COMPLICATIONS IN BASEMENT REFLECTION CORRELATION*

W. D. CORTRIGHT†

ABSTRACT

This paper shows by illustration how the top of basement reflection character correlation may be misleading, and suggests some geologic conditions which may have a bearing on the problem. Local migration vertically of the typical "*Z*" basement reflection, although a disturbing factor, does not prevent the extended use of this reflecting band as a basis for regional mapping of the top of basement horizon.

The "*Z*" bed, or basement reflection, provides a valuable tool for regional mapping. It should be pointed out, however, that its use for detailed mapping is limited by several complicating factors. The purpose of this paper is to look at one of these factors and consider some possible explanations. Three figures consisting of records are shown from a line in the East Hanford area. Please correlate across these figures upward, or from bottom to top in sequence.

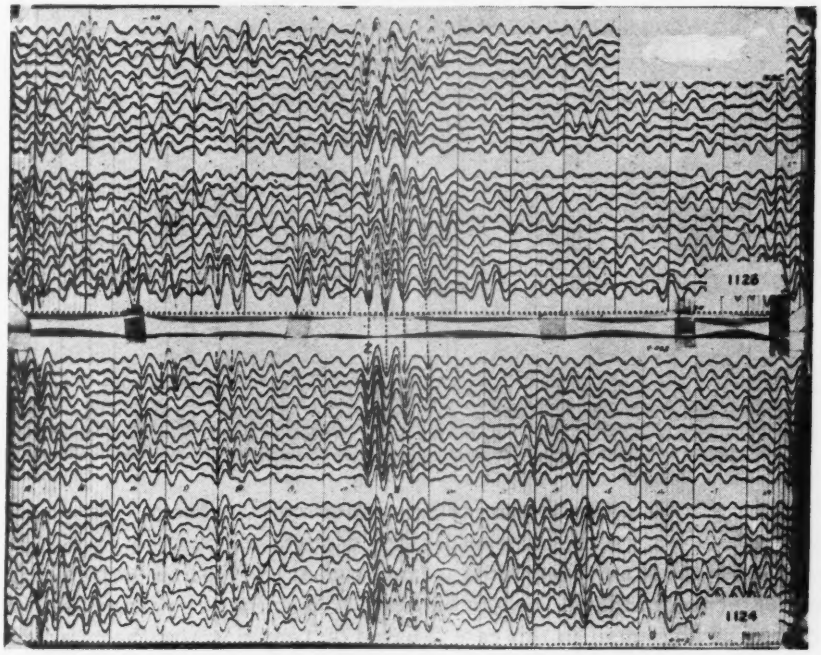

FIG. 1. Basement zone portion of records from two in line shotpoints located 2,000 feet apart with 1,000-foot to 1,000-foot balanced spreads.

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† District Geologist, Tide Water Associated Oil Company, Bakersfield, California.

The deep portion of two nearby, but not adjoining, records is shown in Figure 1. The distance between these shotpoints is 2,000 feet with 1,000–1,000-foot balanced "*T*" spreads. These are 24-trace Western Geophysical Company records taken with corresponding circuits, spreads, offsets, hole depths, and amount of powder. Note the outstanding "*Z*" bed reflection at the center of the plate. These reflections are correlated vertically, taking the first deep trough and succeeding character in each case. Although the character repetition is not perfect, it is a fair assumption that most interpreters would correlate the records as indicated. This correlation is wrong. The error is brought out in Figure 2.

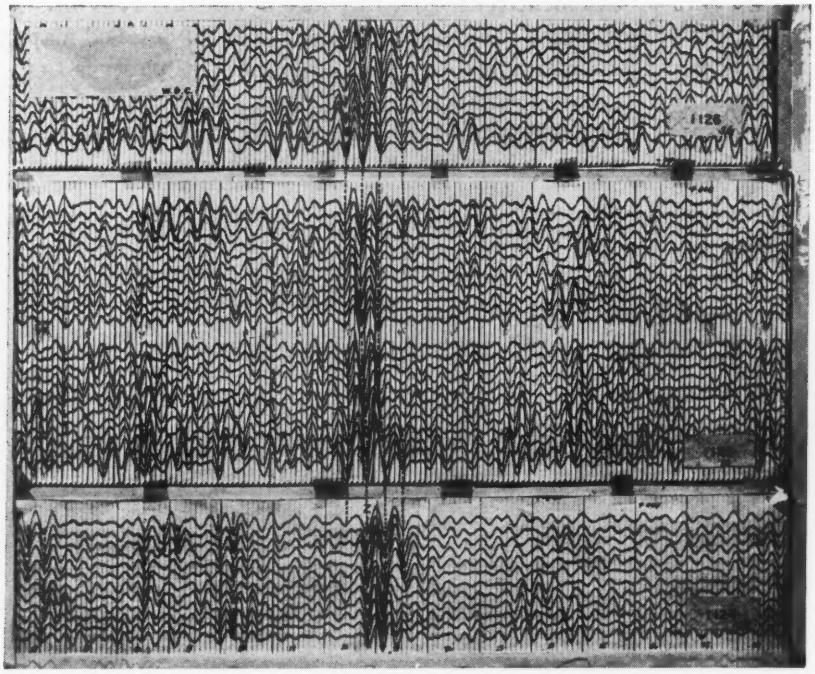

FIG. 2. Same records as Figure 1 plus record filling in gap.

Portions of the same two records are repeated at the top and bottom of Figure 2. The center record fills in the gap between, to complete continuous subsurface coverage. The alignment in this case is based on time ties, together with character correlation. It will be noted that an upper leg development has taken place, beginning at a point near the top of the lower record. Although the appearance of the upper leg is somewhat abrupt, there is little if any reason to suspect faulting. There is instead an indication of the development of a reflecting surface approximately parallel to and slightly above conventional basement.

The last record No. 1126 of this series is repeated in Figure 3, together with

two records from additional points further up on the line. In this figure the continuity of character is present, but you will see the fading out of the first leg on the last half record at the top of the plate. A transition back to the original character, as found at the opposite end of the line, is evident. This reversion back to the original character is spread irregularly across two profiles, but not in a manner to indicate faulting. The presence of a reflecting surface related to, but slightly above the conventional "Z" pick, seems apparent. The indicated separation from these records was computed to be from 135 feet to 200 feet.

These results in cross-section form are presented in Figure 4. The "Z" band

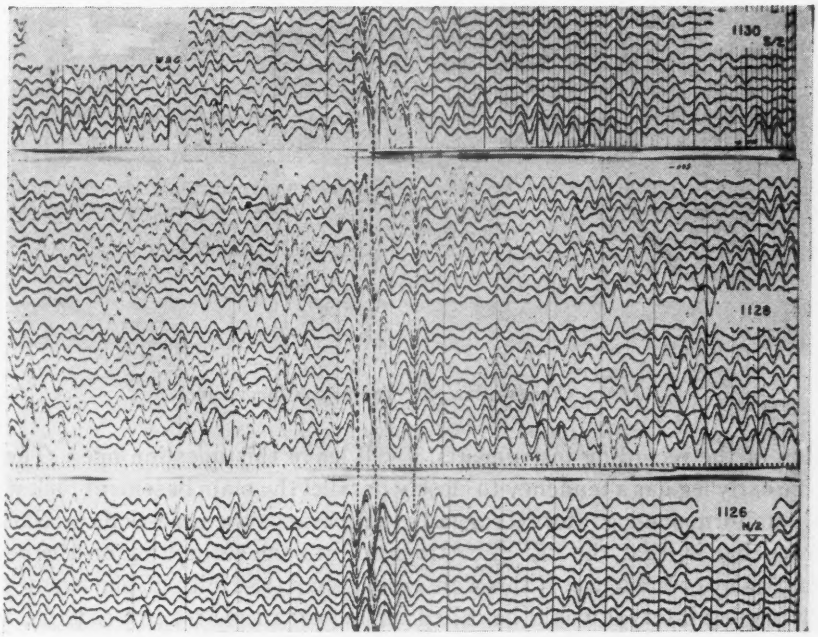

FIG. 3. Additional records from same continuous line.

in question appears at the base of the section near the 8,000-foot level. Observe the slightly higher band across the central part of the section. On profiles immediately adjoining this line to the north, the higher band or upper leg pick is absent. In Figure 5 this cross section is repeated in skeleton form, showing the basement zone relations only.

The origin and significance of this early basement pick presents a problem. I doubt that this is a new problem to many since this condition, or at least like conditions, are not uncommon. Frankly, I don't know the answer, but it will be of interest to speculate.

The first possibility suggesting itself is whether the early arrival actually represents a definite horizon in the formation series, or whether it is a phantom

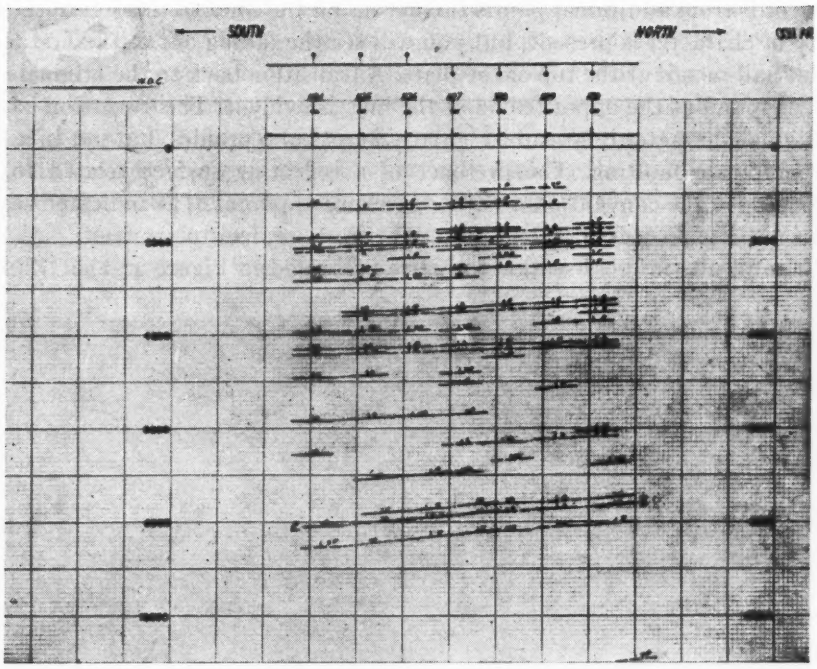

FIG. 4. Cross-section plot of same continuous line.

creation of the recording instruments. I will leave this question open. The fact that the early leg has a tendency to closely parallel the main basement pick within a fairly uniform one-leg interval suggests that perhaps the time-tied correlation is in error; that is, that the "Z" pick time-tie into the second leg on the central records fits by coincidence. If this were true, a sharp rise with displacement equal to the one-leg interval would be called for between the first two records, and a corresponding drop would be needed at the opposite end of the line. I doubt that these faults are present.

Other explanations are based on the varying character of the rocks of the basement contact zone. Within the lower sediments, a local hard sandstone shell or a local, basal conglomerate could provide the contrast needed. Irregular distribution of a regolith member may influence the reflection pattern. Differential weathering and erosion of the basement rock itself may be a principal source of these anomalous reflections. This factor takes on greater importance when we consider that, according to a recent report of J. C. May and Dr. R. L. Hewitt[1] on basement well cores, there are at least eight distinct rock types represented in the basement complex of the San Joaquin Valley. The combination of varying

[1] J. C. May and R. L. Hewitt, "Basement Complex in Well Samples from the Sacramento and San Joaquin Valleys, California," *Calif. Jour. of Mines and Geol.*, *44*, No. 2 (April, 1948), 129–158.

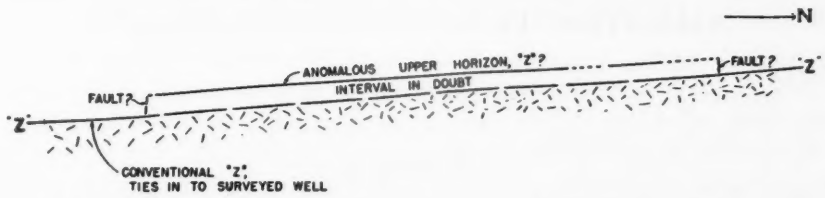

FIG. 5. Skeleton outline of basement zone portion of cross section in Figure 4.

primary rock types, together with variable erosion and weathering as well as variable overburden, covers a wide range within which suitable conditions could exist for the development of this anomaly.

There are doubtless other conditions equally plausible which are not included in the above list. Valuable data pertinent to this subject should be obtainable from a detailed study of the basement reflection pattern in the vicinity of cored wells with measured velocities.

Although erratic character and intermittent occurrence of the "*Z*" bed reflection are disturbing factors, they have not prevented the extended use of this band as a tool in basement contouring. A solution of the problem of the anomalous early leg should add to the effectiveness of this method.

WELL VELOCITY SHOOTING IN CALIFORNIA*

ROBERT J. WELLS†

ABSTRACT

Sources of error and approximate magnitudes of errors are summarized, and the disturbing and misleading effects of impulses transmitted down the well geophone cable are discussed in detail. Several examples of the latter phenomenon in California are shown, and analyses are made indicating the probable path the energy travels from shot to the cable, and thence down the cable to the geophone. Suggested refinements to overcome this trouble are presented.

INTRODUCTION

Well velocity shooting is the most accurate and direct method of getting velocity data for use in seismic interpretations at the present time. Almost every day we find ourselves dependent upon accurate velocity control in order to produce reliable subsurface seismic maps. Consequently today most deep wildcat wells are shot for velocity if at all possible. Because of this need for velocity data, more than two hundred California wells have been shot for velocity information in the past twelve years by the various oil companies and geophysical contract companies for the Cooperative Well Velocity Surveying Group. In practically all cases the same general technique has been used—that of lowering a geophone into the borehole on the end of an insulated multi-conductor cable such as Schlumberger or Lane-Wells use for their electrical logging device. This is the universally accepted method and seems to give satisfactory results in the majority of cases. But as might be expected, there are certain errors inherent in this method of obtaining velocity data, a few of which will be mentioned here.

SOURCE OF ERRORS

The following is a list of 9 of the more obvious errors and their probable magnitude:

1) Geophone depth measurement with a possible error of 20 feet which may amount to 0.002 or 0.003 of a second on the *T-D* curve, and probably is not very serious, except in computing interval velocities for short depth intervals.

2) Charge depth measurement with a possible error up to 50 feet depending upon hole depth, charge size, number of charges fired in the shot hole, and amount of fluid in the shot hole. Generally the error will not be greater than 15 feet or 0.003 of a second. Where the charges tend to float, the error may become quite large, in particular where the charge rises above the subweathering material so that a portion of the energy path is through low-velocity formation. This error can be corrected by use of uphole and reflection geophones.

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† Richfield Oil Corporation, Bakersfield, California.

3) Increased time due to hole shattering may amount to 0.005 of a second or more when a hole has been shot several times with large charges. This error can also be corrected by use of reflection geophones near the well.

4) The subweathering velocity correction error is generally quite small if the charge depths do not vary between wide limits and are well below the weathered layer. This error is usually less than 0.003 of a second and hence of minor importance. If the charges are fired in the weathered layer, then the error may be quite large and not easily corrected for without the use of reflection geophones. The last three errors mentioned can be corrected rather easily by using three or four groups of reflection geophones as correction time checks for the velocity shots. This is accomplished by setting out four groups of seismometers at some convenient location such that the reflection energy paths approximate the well geophone to shotpoint energy paths. The four seismometer groups are laid out as a portion of a regular reflection spread layout and left at this location for the entire velocity run. These four groups will then appear on four separate traces on each velocity shot recording and can be used for time correction purposes. To do this, several reflection times are picked on each record and these are compared with the reflection times on the deepest, generally the first record, shot which is used as the standard for that hole. This amounts to correcting all well geophone times for any one shot hole to the depth of the deepest charge. Since all times are corrected to the deepest shot, the $\Delta sd/V_1$ correction will be the *same* for any one hole and is applied after the time path has been converted to a vertical path by the usual cos i method, where Δsd = difference in elevation between shot and datum plane, and V_1 = subweathering velocity obtained from uphole times or previous shooting in the area.

The advantage in this method over the usual method of correcting each shot to the computation datum by the $\Delta sd/V_1$ formula is that errors due to hole shattering and charge depth measurements are eliminated or compensated for. Since we are using a time correction path below the shot, we can correct for the time delay that affects the time to the well geophone and in this way correct for most of the serious errors introduced at the shotpoint.

5) The error due to borehole drift may be appreciable if the hole is inclined at shallow depths, but for deep surveys the error is probably less than 0.002 of a second.

The drift in deep shot holes may amount to 20 percent of the hole depth which would be a maximum of 0.010 to 0.012 of a second at shallow depths, depending upon direction of drift. This error would decrease with depth of the well geophone and approaches zero for deep velocity surveys.

6) The error in picking the first break or energy onset point on the seismograph trace can become quite large for very low energy impulses and would be a maximum if the first leg were dropped completely. This would give a possible error of 0.008 to 0.015 of a second which may be cut down by using several traces with different filter and amplitude settings on each trace to help pick the point of

onset. Generally this picking error is less then 0.005 of a second and with good breaks is less than 0.001 of a second.

7) The computational error due to straight path assumption has been discussed frequently by Stulken,[1] Dix[2] and others, and hence will not be gone into here. It may be serious only for shallow depths and long offset distance.

8) Casing breaks are noted on some of the cased wells shot for velocity data, and since the majority of wells shot are not cased, this error has not been very serious. Where casing breaks do give trouble, long shotpoint offsets may help do away with the early casing impulses.

9) Finally we get to the error of greatest magnitude and one that gives considerable trouble on numerous velocity runs, that is, cable-borne impulses. Approximately one in every five wells shot for velocity in California appears to have either early energy arrivals evident on the record or an anomalous shift in the *T-D* curve along with a jump in the average and interval velocity curves. Fortunately this shift occurs at about a depth of 3,000 to 4,000 feet, and therefore is not as serious for the deeper portion of the hole as it is throughout the shallow section.

CABLE-BORNE ENERGY

Seismologists have given several explanations for these early arrivals. The simplest and most plausible seems to be that the disturbing condition is caused by shotpoint energy traveling along a portion of the well geophone cable instead of entirely through the formation.

Points 1 to 8 will not be discussed further, but an analysis of well shot data will be presented to prove that most of the shallow anomalies in this type of velocity data are caused by the cable energy path, and that cable energy may also cause trouble in the deeper well velocity data.

The first indication of possible cable path energy was noticed a number of years ago when the large shift in time vs. depth curves indicated a sudden change in energy path such as a high-speed stringer might produce.

A copy of the *T-D* and velocity curves from Cooperative Well Velocity Surveying Group report No. 87 (Richfield Oil Corp. Stone-Bragg No. 1) is shown in Figure 1. It is characteristic of some forty other C.W.V.S.G. reports that show a similar shift in the time-depth curve. Upon examining the curves it is quite apparent that the upper portion of the *T-D* curve has been shifted to the left, which is toward the zero time axis. This must be due to the energy traveling through high-speed material for all or a portion of the path.

Another clue to the cause of the anomaly was the observation of approximately constant uncorrected time intervals of 0.050 to 0.055 of a second for 500-feet depth intervals along the portion of the curve above the shift in the apparent

[1] E. J. Stulken, "Ray Curvature and Seismic Interpretations," *Geophysics*, X (October, 1945), 472–486.

[2] C. Hewitt Dix, "The Interpretation of Well Shot Data, II," *Geophysics*, X (April, 1945), 160–170.

energy path. These constant intervals give a velocity of about 9,000 to 10,000 feet per second, assuming a vertical travel path such as the geophone cable path would afford. Since cable energy was suspected, a number of oil companies conducted cable velocity tests when making velocity runs for the Cooperative Group. Results of these cable tap tests checked the above time intervals very closely, with cable velocities varying from 8,000 to 9,700 feet per second, with the average about 9,300 feet per second.

Another fact brought out by the cable tests was that considerable energy had to be imparted to the well geophone cable in order to get cable breaks to a depth

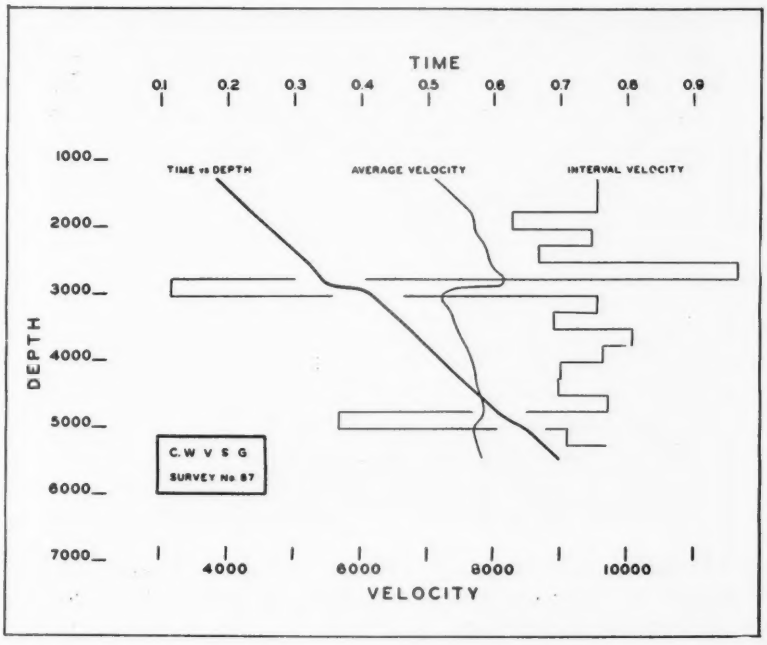

FIG. 1. Plot of velocity data obtained from survey made in Richfield-Stone-Bragg #1 well showing shift in Time-Depth curve.

of 3,000 feet. This checks with observed well velocity data for the shallow portion of the curves, since most of the offsets in the time-depth curves occur between 3,000 and 4,000 feet, indicating that the cable energy must be almost dissipated at a depth of 4,000 feet, and from this point on down the formation energy gives the strongest impulse.

In Figure 2 a group of records from C.W.V.S.G. report No. 87 (Richfield Oil Corp. Stone-Bragg No. 1) show quite clearly how the cable-borne energy is attenuated with depth. At 2,250 feet the onset is sharp and distinct while it gets progressively weaker until at 3,000 feet, the first leg cannot be picked. At this

point the formation energy can be picked, since the cable impulse does not obscure the formation energy onset as is the case for the shallower shots. Finally at 3,250 feet the cable impulse has almost died out, leaving the formation impulse sharp and distinct.

As shown here, picking of the onset of seismic impulses can be very difficult when dealing with low-energy breaks, as is so often the case in well velocity data. It appears that the main part of the energy does not travel in the first trough of the impulse, but probably rides in the second or third leg. Hence, as the energy dies out, the point of onset drops off first so that the later portion of an

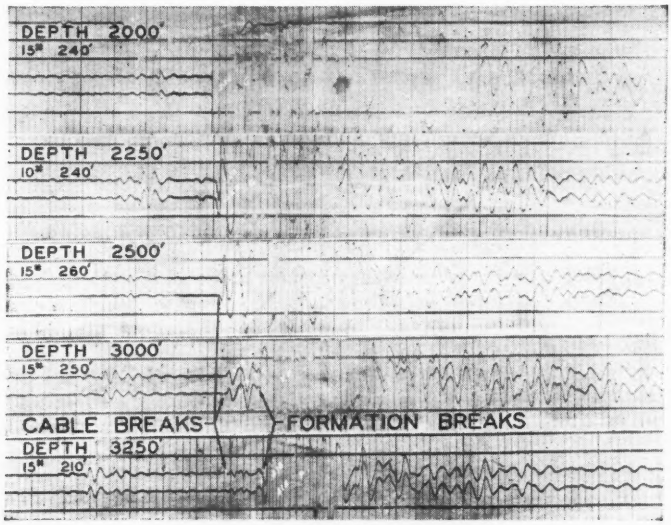

FIG. 2. Records obtained in the shooting of Richfield-Stone-Bragg #1 well showing cable breaks becoming progressively weaker to a depth of 3,250 ft., with the formation breaks definitely arriving at 3,000 ft. and being well defined at the 3,250 ft. level.

impulse is the last to die out as the energy is attenuated; consequently the point of onset or first breaks of weak seismic impulses cannot be picked accurately and may be considerably in error.

Modern well shooting technique calls for the well geophone to energize three or four traces with different energy levels represented on each trace, covering a high-to low-amplitude range. In this way, one can follow with more certainty the change in character and amplitude of the impulses as the energy drops off with depth in well velocity shooting. Also, different filter settings are being used in addition to the amplitude variation in order to facilitate the picking of the correct onset point.

Another sidelight on the cable-borne energy problem occurred when two wells were shot with a dual seismometer hookup, which is the placing of two geophones

on one cable, with the lower one separated by 200 feet of cable from the upper one. In this way continuous velocity recordings of wells have been made using 200-foot intervals. Here the lower seismometer should check the position occupied by the upper one on the previous shot, and this procedure would be followed for the entire well depth. Cooperative Group report No. 111 represents data obtained with the dual seismometer hookup, but in this case the ΔT for the 200-foot intervals is 0.021 of a second for almost all shots where the 200-foot interval is recorded by one shot on a single seismogram. In other words, the energy traveled from the upper geophone down the 200 feet of cable to the lower geophone, and the time for this 200 foot cable path was 0.021 of a second, which gives

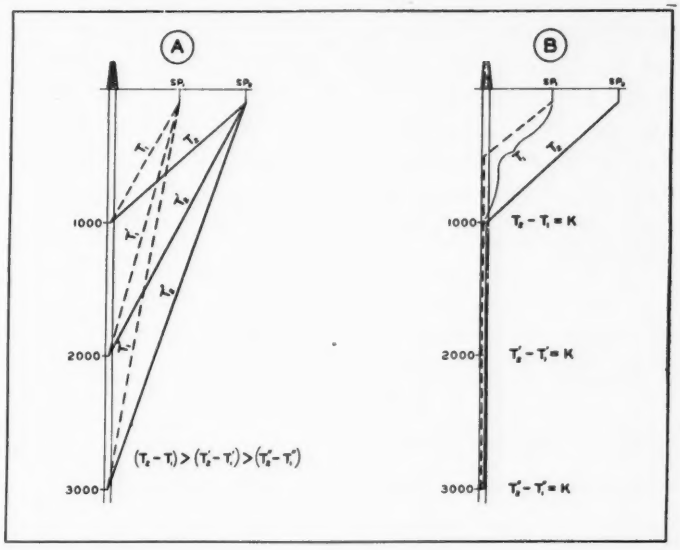

FIG. 3. Energy path diagrams showing normal formation path at (A) and a cable energy path at (B).

a velocity of 9,520 feet per second for the piece of cable separating the two geophones. Because of this high-speed energy path, the interval velocities do not work out in a reasonable pattern, and the lower seismometer does not check the time of the upper one for the same position at any point in the run. Group report No. 110 is similar to No. 111, but not quite as obvious, since only half of the shots show the ΔT of 0.021 of a second for the 200-foot dual seismometer interval.

From all this evidence it seemed quite certain that the cable was the cause of the anomalous condition mentioned previously, and so it became necessary to check the actual energy path to prove conclusively that the energy was entering the cable above the well geophone. As Dr. C. Hewitt Dix[3]) has pointed out, two

[3] *Ibid.*

or more shot holes at various distances from the well are necessary; and shots must be taken with the well geophone at several common depth points in order that an accurate time difference for various common depth points may be obtained.

As can be seen from the diagrams in Figure 3, when only the formation energy path is involved as at (*A*) and the formation velocity is constant with depth, the uncorrected travel time differences T_2-T_1 vary with depth such that T_2-T_1 is greater than $T'_2-T'_1$ which is greater than $T''_2-T''_1$. In other words, the time difference of the two paths decreases with depth, while if the energy is traveling the cable path of (*B*) and the cable velocity is constant with depth, the T_2-T_1 difference is a constant and remains constant as long as the energy from both shot holes follows a cable path such as that shown in (*B*) of Figure 3.

Two good examples of this two-hole offset shooting are Group surveys No. 135 and No. 138. In both cases the ΔT's are constant as well as the T_2-T_1 differences being constant for a common geophone depth point confirming the theory that energy is traveling the lower portion of the cable to the well geophone.

Table 1 represents data from survey No. 135 to show how closely the ΔT's check when the geophone depth measurements are accurate and the charges are all at the same depth.

TABLE 1

Shot Depth	Geo. Depth	T_2	ΔT_2	T_1	ΔT_1	T_2-T_1
110 ft., —	1,500	0.205		—		
			0.053			
110 ft., 110 ft.	2,000	0.258		0.230		0.028
			0.053		0.054	
110 ft., 110 ft.	2,500	0.311		0.284		0.027
			0.055		0.054	
110 ft., 110 ft.	3,000	0.366		0.338		0.028
		$H=500$ ft.		$H=250$ ft.		

H = horizontal distance of shotpoint from well.

It is obvious that the record picking and shot hole corrections have to be very accurate in order to check such small differences. The time of 0.311 second at 2,500 feet probably should be 0.312 second, only 0.001 second off. If so, all but one of the ΔT's would be 0.054 and the T_2-T_1 values would all be 0.028 of a second. This agreement is considerably better than can be expected with the usual velocity data, since variations in the charge depth, hole shattering and geophone depth measurement inaccuracies can cause variations of ± 0.005 of a second, which normally makes most well shooting data almost useless for the purpose of checking shallow energy paths. However, in this case the T_2-T_1 values are constant, thus verifying the fact that the energy must travel some such cable path as shown in diagram (*B*) of Figure 3. The cable velocity in this case computes at 9,260 feet per second.

Another set of velocity data that also proves the cable energy path very well is from Group survey No. 138 and is shown on Table 2.

TABLE 2

Shot Depth	Geophone Depth	T_2	ΔT_2	T_1	ΔT_1	T_2-T_1
64 ft., —	1,000	0.221		—		
			0.055			
59 ft., 62 ft.	1,500	0.276		0.232		0.044
			0.054			
58 ft., —	2,000	0.330		—	0.109	
— , 60 ft.	2,500	—		0.341		
			0.110			
60 ft., 60 ft.	2,750	0.412		0.367	0.056	0.045
61 ft., 60 ft.	3,000	0.440		0.397		0.043
		H=1,000 ft.		H=600 ft.		

H=horizontal distance of shotpoint from well.

The data in this case fall into a pattern similar to survey No. 135, while here the shotpoint offset distances were 600 feet and 1,000 feet, and to add final proof of the energy path, a cable tap velocity test was made which checked the cable velocity from well shooting almost exactly at 9,160 feet per second.

Since it appears that we do have shotpoint energy traveling the geophone cable at times during well velocity runs, it is instructive to check the most probable energy path from the shotpoint to the cable.

At first sight it might appear likely that the energy entered the cable at the

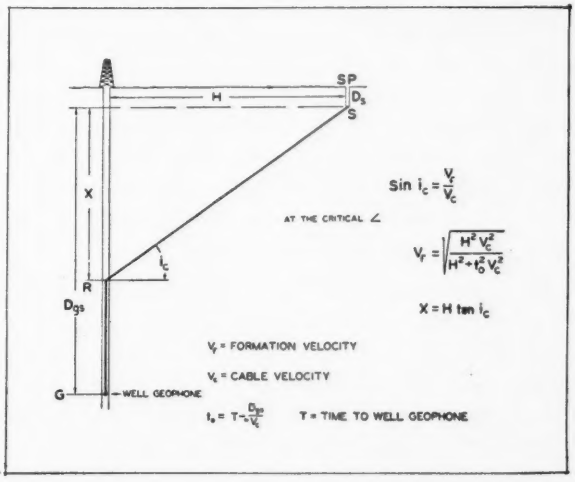

FIG. 4. Diagram showing critical angle of refraction (i_c) at which energy enters the well geophone cable, and formulae for computing this angle.

casing shoe or through some hard formation such as sandstone or shell layer. This path seems feasible, but in almost all cases the formation velocity from the shotpoint to the cable appeared too high, indicating this is not a minimum time path.

Another possibility is that the energy enters the cable by refraction at the critical angle. The refraction path also gives a better explanation for the energy needed to get an impulse 3,000 feet down the well geophone cable, because at the critical angle of refraction a reinforcing of energy takes place in the high-velocity medium, in this case the cable, that can account for the energy level needed.

The critical angle of refraction illustrated in Figure 4 can be computed from Snell's law—Sin $i_c = V_f/V_c$ if the two velocities are known. In the usual case the cable velocity is known and the formation velocity for the path shown is only known approximately from uphole times. To obtain the formation velocity accurately, the following variation of the refraction depth formula can be used:

$$\text{Formation velocity, } V_f = \sqrt{\frac{H^2V_c^2}{H^2 + t_0^2V_c^2}},$$

where H = shotpoint offset distance,
V_c = cable velocity,
t_0 = cable intercept time.

After computing the velocity of the formation path from the above formula, the critical angle can then be calculated and used in the $X = H \tan i_c$ formula to obtain the depth point at which the shot energy enters the geophone cable.

This formula has been applied to a number of wells and gives a value for the formation velocity in very good agreement with the values obtained by uphole shooting, surface refraction shooting and long-offset well velocity shooting. This is taken as proof that this hypothesis as to manner in which the energy enters the cable is the correct one.

It is interesting to note that the critical angle (i_c) in the case of short offsets (500±) works out to be about 40°. Thus for a shotpoint distance of 500 feet, the point of maximum energy entry into the geophone cable will be approximately 400 feet below the depth of shot. The reason for the consistency of "i_c" for short offsets, is that it is determined by velocities that vary between rather narrow limits in California; consequently we can predict before a well is shot the most probable point at which energy will enter the cable.

From an examination of well velocity data, it is apparent that shotpoint offset distances of 1,000 feet or less are most likely to give cable breaks; also, the shorter offset distances such as 250 feet produce the greatest shift in the *T-D* curve at a depth of about 3,000 feet, because practically the entire energy path is a high speed cable path. With shotpoints located 1,200 to 1,500 feet from a well we find cases, depending on the ratio of formation velocity to cable velocity, where the cable breaks and formation breaks produce almost identical corrected time-depth

curves. In such cases it is practically impossible to definitely isolate the different energy paths when only the one offset distance is used; thus shotpoints should not be offset such that cable breaks fall close to formation breaks, since there might be no offset in the curves to cause suspicion. Very few cable breaks are noticed with shotpoint offsets of 1,500 feet or more, which is probably due in part to the attenuation of energy by the longer formation path to the cable refraction point. In the case of fairly high formation velocities at the 1,500- to 3,000-foot geophone depths, the formation breaks come in ahead of the cable breaks at practically all geophone levels. Long offsets of 1,500 or 2,000 feet generally will do away with the majority of strong cable impulses, thus making the picking and interpretation of true formation breaks much easier. The long offsets may increase the computational error of straight path assumption mentioned previously; however it is the writer's opinion that this error is small even at shallow depth.

The question arises: Why don't we have cable breaks on all well velocity shooting runs? This is not an easy question to answer, because of all the variables involved. Some of the more obvious things that affect the energy path in the order of importance are:

1) Cable velocity and formation velocity; when the formation velocity approaches the cable velocity it is impossible to have cable impulses ahead of the formation energy, since the minimum time path is entirely in the formation.
2) Cable tension due to weight of the cable and the weight attached to the well geophone. This factor is probably important in that it affects the attenuation of energy down the cable.
3) Type of formation at the shotpoint, such as sand, shale, clay, etc.
4) Characteristics of the energy generated at the shotpoint, such as wave form and frequency, these being affected by depth of shot and charge size as well as the material the shot is fired in.
5) Mud density and temperature and viscosity since these affect the attenuation and dispersion of waves carried by the cable.

With present equipment the best method for avoiding cable impulses is to drill holes at two or three different offset distances such as 500, 2,000 and/or 2,500 feet. If two or three shotpoint offset distances are used, one of them will probably give better results than the others. When this is observed during a velocity survey the majority of shots should be taken from holes at this offset distance, and time-depth values should be plotted accurately as the survey progresses in order to be able to detect cable or casing energy paths, as well as to determine the best offset distance. If only two distances are used, the 500-foot and 2,000-foot offsets are probably the best with most of the shallow velocity data obtained from the 2,000-foot offset hole. Generally the short offset cable energy will lead the formation breaks on the record by enough time so that the correct velocity impulses may be picked below 2,500 feet. The 2,000 foot offset

breaks will not be bothered with cable impulses until a depth of ±2,000 feet is reached, depending upon the formation and cable velocities. Even then the early impulses may be too weak to confuse the picking of the true breaks.

Numerous velocity runs have early impulses at depth, which are probably caused by cable or casing energy paths. In general these breaks will not fall into the pattern of shallow cable breaks, for at depth the energy does not enter at the same depth point for each shot, but appears to enter the cable or casing 300 to 500 feet above the geophone, thus producing an impulse just ahead of the true one. This early energy can be troublesome and difficult to analyze. It is probable that the ratio of formation velocity to cable velocity is the main factor in determining the point of energy entry and strength of the deep cable impulses.

CONCLUSIONS

An analysis of well velocity data has been presented to prove that most of the shallow early impulses are caused by cable-borne energy. Also, that the approximate refraction path for this energy can be predicted and then computed from the observed well velocity data, and that cable impulses can be almost entirely eliminated by shot holes offset 2,000 ft. from the well.

There are many interesting problems in connection with well velocity shooting that have not been dealt with here and it is hoped that this paper will lead to a discussion of some of the other aspects in the future.

ACKNOWLEDGMENTS

The writer wishes to thank Richfield Oil Corporation for permission to prepare and publish this paper; T. P. Ellsworth, J. W. Mathews, C. H. Johnson and the many others for their advice and assistance; and E. L. Jue for the preparation of the illustrations.

A NOTE ON MULTIPLE REFLECTIONS*

G. E. HIGGINS†

INTRODUCTION

It was most interesting to read the January 1948 issue of *Geophysics* which was devoted to articles on multiple reflections and I would endorse the plea of Mr. Robert H. Mansfield[1] for an issue of *Geophysics* to be devoted to the troublesome problems of offside energy in seismic prospecting.

Trinidad has recently been the scene of intensive geophysical investigation, both gravimeter and reflection seismic, and while neither method gives unambiguous answers to the local geologic problems, it is about the reflection seismic results which I should like to discuss.

The first period of intensive seismic investigation in Trinidad was during 1938–1939 and certain anomalies observed then received further investigation during 1946–1947. During both periods of investigation, two particular phenomena were observed which may be called:

1. Near-shore effect.
2. Coning.

NEAR-SHORE EFFECT

Steep offshore dips were recorded in the earlier surveys from seismic profiles run on land along the Gulf of Paria. Opinion differed as to the reliability of such dips but in the opinion of some, the dips were indications of faulting.

During the more recent surveys, steep offshore dips were again recorded from a seismic profile located inland and within 1,000 or so feet of the Gulf. The plotted dips from this survey are suspect for they are completely contrary to the regional landward trend as deduced from surface geology.

There is no known fault or hydrographic feature etc. from which the energy might have been returned and attempts to resolve the data using combined reflection and refraction paths with the water-recent mud interface as a reflector have not proved particularly helpful.

CONING

This is Trinidad's most troublesome problem. At the present time coning seems to occur to varying degrees over any particular profile that Trinidad Leaseholds Limited have shot.

It is manifested as a curving or arcing of the strike lines of the plotted seismic dips about the shotpoint. In some cases the phenomenon is so severe as to indicate a series of circular basins along the seismic profile, each shotpoint or a series of consecutive shotpoints being the center of the basin. In plotting this information onto cross sections the basin appearance may be quite marked. In this case "calotting" has been suggested as a more suitable term. Figure 1 illustrates the coning phenomenon as observed when the recorded reflections from one shotpoint

* Manuscript received by the Editor, February 7, 1949.

† Trinidad Leaseholds Limited, Pointe-a-Pierre, Trinidad, B.W.I.

[1] Robert H. Mansfield, "The Offside Energy Problem in Seismic Prospecting," *Geophysics*, XIII (July, 1948), 457–458.

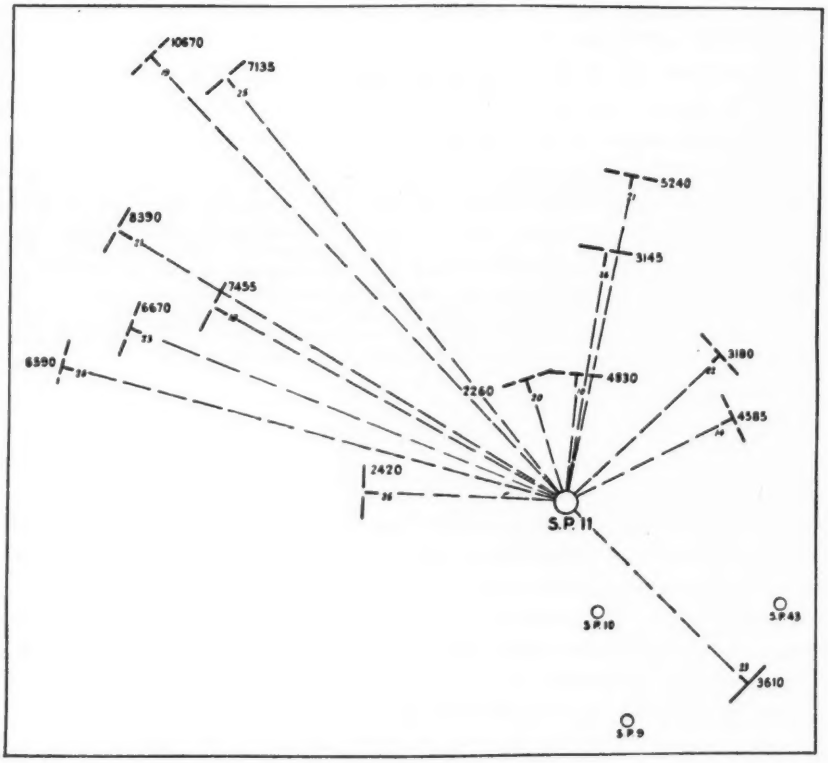

FIG. 1. Illustrates coning phenomenon as observed when the recorded reflections from one shotpoint (S.P. 11) are plotted.

(S.P. 11) are plotted. The confusion, when consecutive shotpoints yield similar patterns, can be easily appreciated.

It might be thought that separation of the dips into different levels, e.g., 2,000 ft., 2,000 ft.–4,000 ft., etc., would reduce the apparent effect but this has been tried without success.

Attempts to ascertain the cause or resolve the phenomenon to any extent have proved unsuccessful, but it is possible that it may be bound up with offside energy problems, at least in some aspects.

Some pertinent remarks about the seismic data and computation are as follows:

a) Our records are generally poor on the average but even good records have shown coning to some degree.
b) The frequency of the plotted reflection events occur within the normal reflection frequency range.
c) Continuity of reflections is rare; nonpersistence of reflections is the rule.

T.L.L. (Trinidad Leaseholds Limited) adopted the method of continuous profiling in their surveys.

d) There is no obvious means of distinguishing the reflections which might appear "coned" when plotted, from other reflections on the record, e.g., opposite dip appearance from other reflections, although this is shown in isolated cases. Coning further appears at all levels, though in some areas the phenomenon appears accentuated in the more shallow-recorded reflections.

e) The most severe case of coning showed up in plotting data computed from "mixed" records, but a revised computation from "unmixed" records still showed coning though to a lesser degree.

f) Least square method was applied to Δt determinations with graphical plots in the more suspect cases.

g) Both straight-path (corrected for overburden effect) and curved-path calculations were used. Coning is apparent with either method.

h) As a whole, Trinidad is an area of low-average vertical velocities. Interval velocities are often irregular, particularly in Miocene sandy areas, with the lower velocities being recorded in sands.

In searching for the cause, all computations were rigorously checked and the possibility of human errors eliminated.

Other causes might be: Near surface or subsurface.

NEAR SURFACE

Generally speaking, we can neglect the effects of weathering, for it is common to all recorded reflections except where the dips are exceptionally steep and the reflected ray paths through the weathered layer would be expected to differ considerably from the reflected paths from gentler dips.

SUBSURFACE

The bulk of the shooting was carried out in the Barrackpore-Siparia syncline area where the Miocene rocks are composed of alternations of sands, silts and clays of deltaic origin. The thickness varies from zero on the flanks to $\pm 8{,}000$ ft. in the basinal area. The sands are irregular and erratic in their distribution and are known to be lenticular, sometimes slumped, strongly cross-bedded and even foreset bedded in certain zones. The Lower Miocene is dominantly clay, becoming calcareous towards the base. The underlying Oligocene is composed of a neritic series of clay and marls, frequently interfingering, with occasional sand intercalations. In the uplifted areas the Miocene rests unconformably on the Oligocene—basinwards sedimentation may have been continuous throughout Oligocene and Miocene. There are indications of an unconformity in the upper part of the Miocene section. However, coning is not exclusive to profiles shot in the Miocene deltaic areas; we also get it in the profiles shot in Oligocene clay, calcareous clay and marl areas.

One explanation may be that the seismic energy instead of being, as is assumed, contained in plane normal to the reflection, travels rather through a series of skew planes, being diverted in various directions as it travels down to the reflector and back to the surface. This is similar to visualizing a sequence of unconformable beds with sufficient elastic differences in the formation to provide for changes in direction.

As a check on coning, a survey was made in an area where good well control was available. It was shown there that some of the apparent coning effect was quite valid for the reflections appeared to be coming from sand horizons which were cross-bedded within the formation. In this instance the assumption of the wave path being contained in the plane normal to the reflection appears valid. Unfortunately, the most severe coning occurred in an area outside the well area and could not be checked, and it was still difficult to decide whether the agreement of well and seismic data elsewhere was not a question of chance.

From the point of view of the geophysicist, he is entitled to say for the want of concrete evidence that the explanation of coning is the simple one that the reflecting planes do exist, whether they be cross or normal bedding planes, lithologic changes, or fault planes, etc. Nevertheless, it is extremely difficult to understand or accept the geologic and/or tectonic picture implied by these dips, and we wonder whether similar conditions have been observed elsewhere.

Whilst there is little doubt that on the mechanical side the seismic method of prospecting has reached a high degree of efficiency, there are many problems on the interpretative side requiring resolution and such articles as the series on Multiple Reflections are a step forward.

ACKNOWLEDGMENTS

In conclusion, the writer would like to acknowledge the benefit of the many discussions with Mr. J. E. T. Woodburn and his S.S.L. staff concerning the seismic problems of Trinidad.

CURVES FOR THE RAPID DETERMINATION OF REFRACTION SEISMOGRAPH VELOCITY INTERVALS AND CRITICAL DISTANCES*

W. B. AGOCS†

ABSTRACT

In refraction shooting it is frequently necessary to make calculations for the thickness of velocity intervals, and estimates of the critical distance for shooting to a particular velocity horizon. In the following paper a set of families of curves are built up based on slope form of the total travel time equation $T_n=(X/V_{n+1})+\sum_{a=1}^{n}(2ha\cos\phi_{a,n+1})/V_a$. The separate times of travel through any velocity interval may be determined from the curves for the sectional velocity and the refracting horizon velocity. These calculations are possible since the velocities encountered in refraction seismic work cover a finite interval from about 5,000 ft/sec to about 20,000 ft/sec. Finally, with the family of curves calculated above, it is possible to determine rapidly the critical distance of shooting for a particular marker horizon if the sectional velocities and their intervals are known approximately. The curves are used to solve the critical distance equation to a particular horizon of the form

$$X_n=[V_nV_{n+1}/V_{n+1}-V_n][\textstyle\sum_{a=1}^{n-1}(2h_a\cos\phi_{a,n+1}/V_a)-\sum_{a=1}^{n-1}(2h_a\cos\phi_{a,n}/V_a)].$$

INTRODUCTION

It is frequently necessary to resort to refraction shooting in order to obtain information on sectional velocities, and on the thickness of these sections. Once the sectional velocities and their thicknesses are known, it is possible to determine the probable velocity function that would best suit the area in question. In addition to using the refraction seismograph as a tool for the reflection seismograph, it is a method for checking broad features where its low resolving power will outline anomalous features. However, for this latter, it is necessary to have sectional thickness determinations, so that the depths to the various velocity horizons may be known. It is not the purpose of this paper to go into detail as to the procedure of refraction shooting techniques and the methods of calculation employed, but to present a method whereby families of curves may be calculated and used for the rapid determination of any distribution of velocities. In addition, these families of curves may be applied to the rapid calculation of critical distances for refraction shooting, where a knowledge of shot length necessary to penetrate to a particular marker is of interest in order to determine the economic possibility of obtaining energy returns.

THEORY

Refraction Seismograph Velocity Interval Determination.—The families of curves for the determination of the thickness of velocity horizons may be calculated, using a limited number of families of curves, since the range of speeds encountered in refraction seismic work lies between a minimum of about 5,000

* Manuscript received by the Editor March 14, 1949.

† Venezuelan Atlantic Refining Co., Caracas, Venezuela.

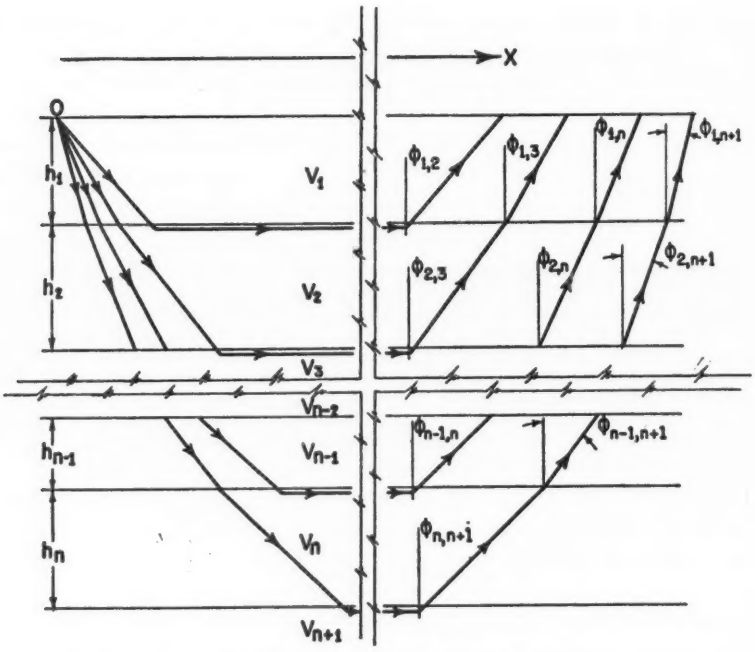

FIG. 1. Wave paths followed by refracted waves.

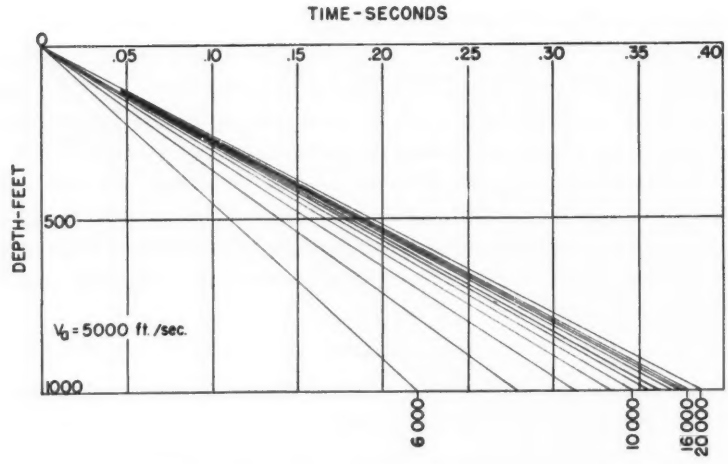

FIG. 2. Time-thickness curves for sectional velocity $V_a = 5{,}000$ ft/sec; refraction velocity increasing to 20,000 ft/sec

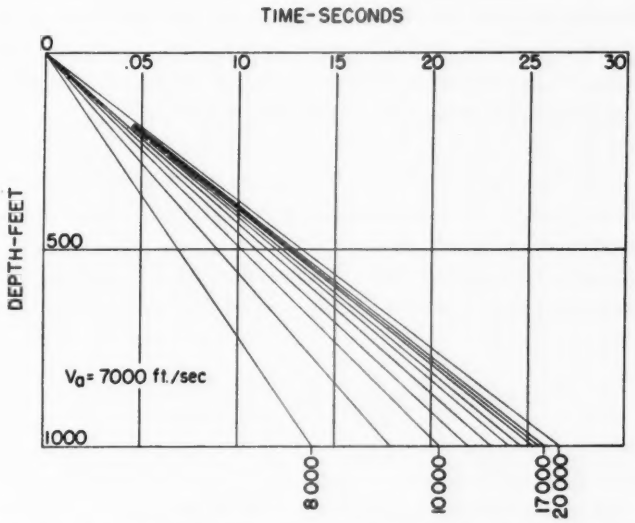

FIG. 3. Time-thickness curves for sectional velocity V_a=7,000 ft/sec; refraction velocity increasing to 20,000 ft/sec

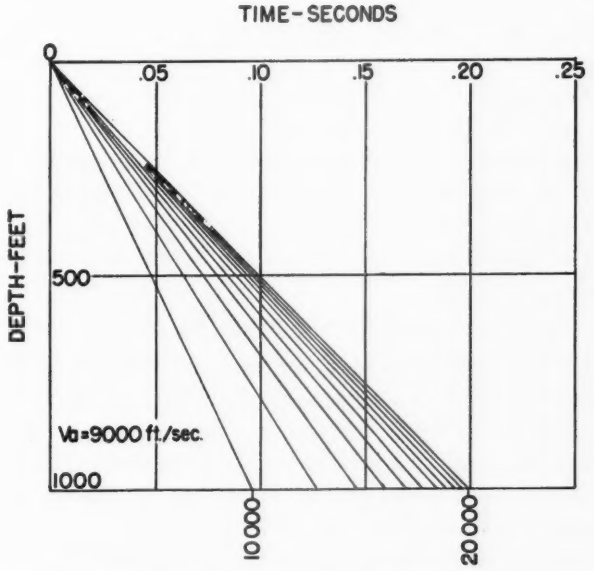

FIG. 4. Time-thickness curves for sectional velocity V_a=9,000 ft/sec; refraction velocity increasing to 20,000 ft/sec

ft/sec and a maximum of 20,000 ft/sec. This range of velocities could be extended slightly, but for the purposes of this paper these figures have been selected. While all possible velocities are existent between the minimum and maximum values, these may be interpolated from the curves which are built up.

The equations which are to be utilized in determining the thickness of the velocity intervals may be found in standard texts on geophysics, although they may be derived readily. The derivations are based on Snell's law, and the discontinuous increase of velocity with depth.

The general equation for the time of travel of a wave from the point of detonation to the recording geophone following one of the paths shown on Figure 1 is found to be

$$T_n = (X/V_{n+1}) + \sum_{a=1}^{n} 2h_a \cos \phi_{a,n+1}/V_a, \tag{1}$$

where

T_n is the total travel time;
X is the distance from the shotpoint to the detector;
h_a is the thickness of the a-th horizon;
h_n is the thickness of the final horizon penetrated;
V_a is the velocity in the a-th horizon;
V_{n+1} is the velocity of the final refracting horizon;
$\phi_{a,n+1}$ is $\sin^{-1}(V_a/V_{n+1})$.

From equation (1), the time intercept equation is

$$T_n' = T_n - (X/V_{n+1}) = \sum_{a=1}^{n} 2h_a \cos \phi_{a,n+1}/V_a. \tag{2}$$

In the form of equation (2), the intercept time is independent of the shot-detector distance X, and depends only upon the thickness of the velocity horizons, the velocities of the horizons, and the velocity of the final refracting horizon. For each factor of the summation of equation (2), it is possible to build up a family of curves of the form

$$t = 2h_a \cos \phi_{a,n+1}/V_a \tag{3}$$

in which equation V_a would be fixed, and $\cos\phi_{a,n+1}$ would be fixed for a particular V_{n+1}, and t would be dependent on h_a for a particular curve of the family. V_{n+1} may be increased in 1,000 ft/sec increments from the fixed velocity V_a for the different curves of the family. A second family of curves could be built up with V_a having a velocity 1,000 ft/sec greater than that for the initial curve, and so on to the maximum sectional speed observed.

Figure 2 is the family of curves obtained using equation (3) when V_a is fixed at a speed of 5,000 ft/sec, and V_{n+1} is increased from 6,000 ft/sec to 16,000 t/sec in 1,000 ft/sec increments.

Figures 3 to 8, inclusive, are the families of curves for V_a ranging from 7,000 ft/sec to 17,000 ft/sec in 2,000 ft/sec steps for V_a between families of curves.

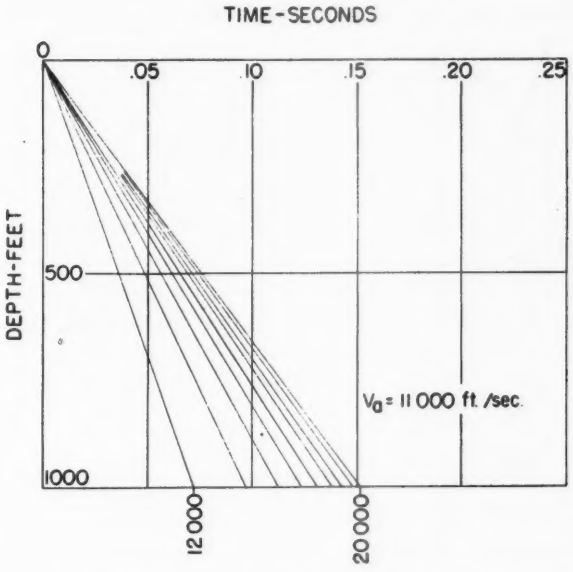

FIG. 5. Time-thickness curves for sectional velocity $V_a = 11{,}000$ ft/sec; refraction velocity increasing to 20,000 ft/sec

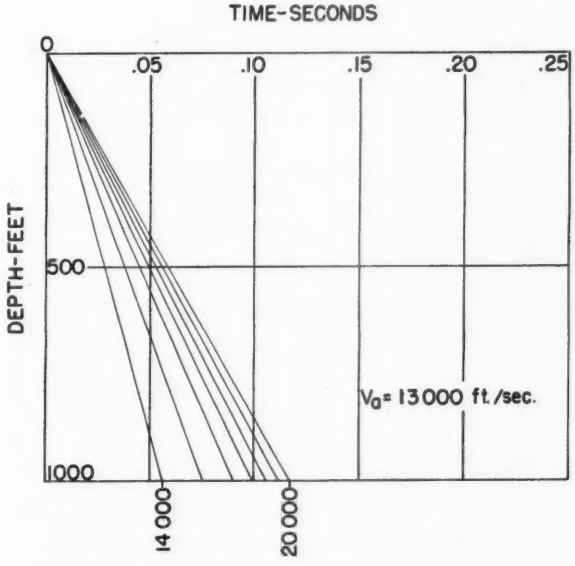

FIG. 6. Time-thickness curves for sectional velocity $V_a = 13{,}000$ ft/sec; refraction velocity increasing to 20,000 ft/sec

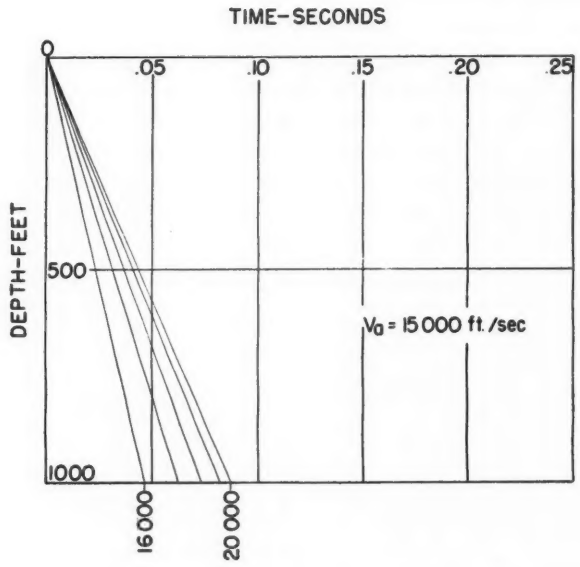

FIG. 7. Time-thickness curves for sectional velocity $V_a = 15{,}000$ ft/sec; refraction velocity increasing to 20,000 ft/sec

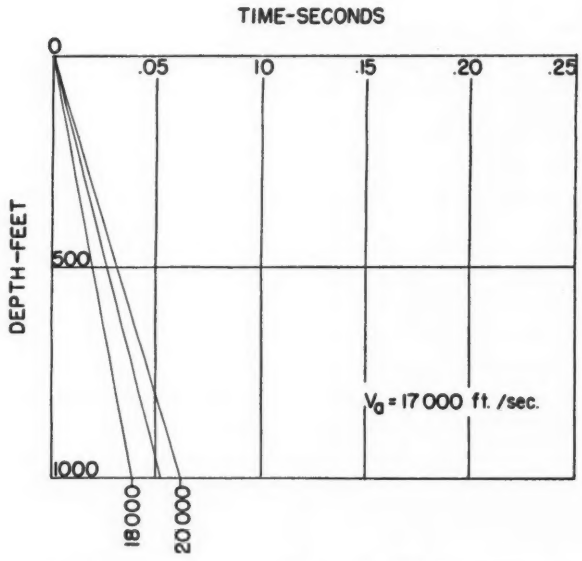

FIG. 8. Time-thickness curves for sectional velocity $V_a = 17{,}000$ ft/sec; refraction velocity increasing to 20,000 ft/sec

The method of using the curves may be simply illustrated by the following problem:

$V_1 =$ 7,000 ft/sec $\quad T_1' = 0.160$ sec
$V_2 =$ 9,000 ft/sec $\quad T_2' = 0.400$ sec
$V_3 =$ 15,000 ft/sec

From Figure 3, it is found that for a V_a of 7,000 ft/sec and a V_{n+1} of 9,000 ft/sec, and an intercept time of 0.160 seconds, the thickness of the first high speed horizon is 890 feet. To determine h_2, we still use the curves of Figure 3, and we find that for a V_{n+1} of 15,000 ft/sec, the time spent in the first high horizon is 0.226 seconds; hence the time spent in the 9,000 ft/sec horizon is the difference between 0.400 seconds, and 0.226 seconds, or 0.174 seconds. For this latter time, from Figure 4, for a V_a of 9,000 ft/sec, and a V_{n+1} of 15,000 ft/sec, h_2 is found to be 970 feet. These values compare well with exact calculations. For general use the curves should be of a sufficiently large scale for precise determinations of time and depth or thickness.

Critical Distance Determination.—The critical distance in refraction shooting may be defined as the minimum distance between the shotpoint and the recording point where totally refracted waves from a horizon are recorded simultaneously with the totally refracted waves from the next deeper horizon. Referring to Figure 9, which illustrates the time-distance curve for the paths followed by the refracted wave, the maximum distance at which waves traveling through the horizon having a velocity V_1 may be recorded as first arrivals, and the minimum distance for recording waves refracted from the horizon V_2 as first arrivals is X_1. The minimum distance, or the critical distance, for recording the wave refracted from the $V_2 - V_3$ interface is X_2; hence the critical distance for recording waves refracted from the V_3 horizon is X_2. At the critical distance, the time of travel of the waves in the lower speed horizon is equal to that in the next higher speed horizon, or

$$T_{c1} = X_1/V_1 = (X_1/V_2) + 2h_1 \cos \phi_{1,2}/V_1. \tag{4}$$

Solving for the critical distance,

$$X_1 = [V_1V_2/(V_2 - V_1)]2h_1 \cos \phi_{1,2}/V_1, \tag{5}$$

if h_1 is postulated, and V_1 and V_2 are known, from the curves of Figures 2 to 8, $(2h_1 \cos \phi_{1,2})/V_1$ which is t seconds may be determined, and X_1 may be obtained using equation (5). For X_2, the travel time through V_2 and V_3 are equal, and

$$\begin{aligned} T_{c2} &= (X_2/V_2) + 2h_1 \cos \phi_{1,2}/V_1 \\ &= (X_2/V_3) + (2h_1 \cos \phi_{1,3}/V_1) + (2h_2 \cos \phi_{2,3}/V_2); \end{aligned}$$

and the critical distance is

$$\begin{aligned} X_2 = [V_2V_3/(V_3 - V_2)][&(2h_1 \cos \phi_{1,3}/V_1) + (2h_2 \cos \phi_{2,3}/V_2) \\ &- (2h_1 \cos \phi_{1,2}/V_1)]. \end{aligned} \tag{6}$$

The general equation for the critical distance is

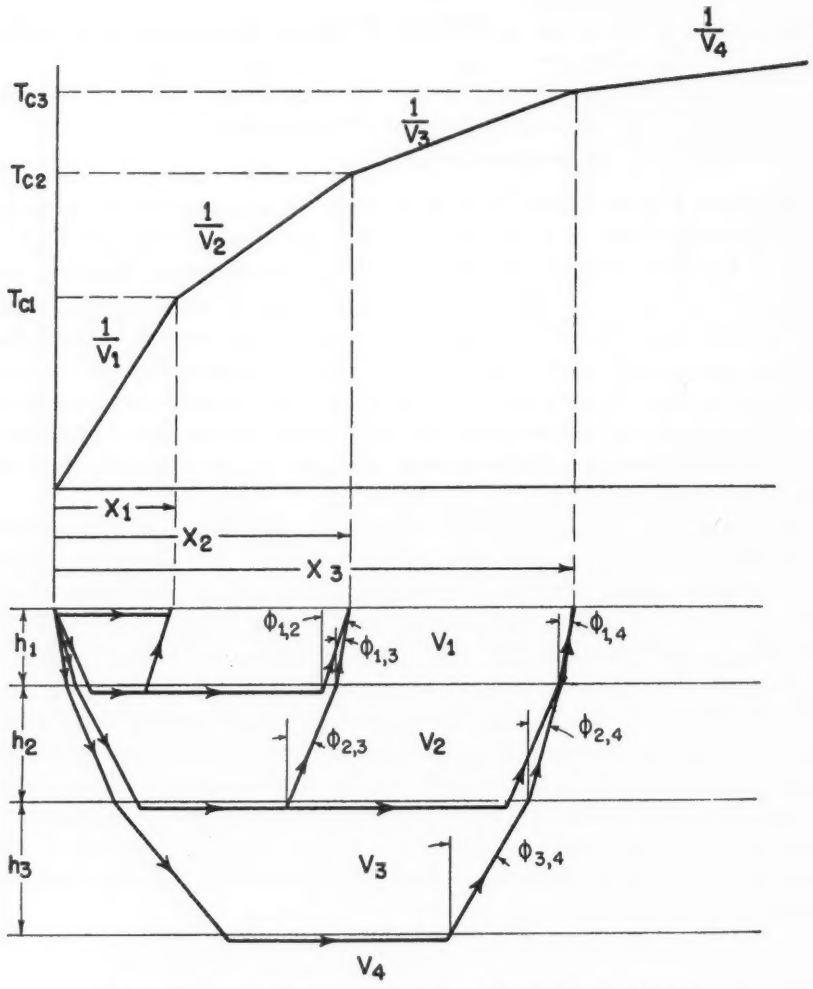

FIG. 9. Time-distance curves and refracted wave curves, showing critical distance conditions.

$$X_n = [V_n V_{n+1}/(V_{n+1} - V_n)]\left[\sum_{a=1}^{n} (2h_a \cos \phi_{a,n+1}/V_a) - \sum_{a=1}^{n-1} (2h_a \cos \phi_{a,n}/V_a)\right]. \quad (7)$$

Each time factor of the summations may be determined for postulated values of the horizon thickness h_a, and associated velocity distributions by using the curves of Figures 2 to 8, and the critical distance X_n for any particular horizon may be determined by multiplication of the result of the summations by the velocity factor.

DISCUSSIONS AND COMMUNICATIONS

(The following is a condensed version of a letter from Mr. Joseph E. Keller to the Secretary of the Federal Communications Commission requesting that the 1,600–1,700 kc. frequencies be kept for geophysical use. It is being published because it is believed that this matter is of interest to the entire industry.)

AMERICAN PETROLEUM INSTITUTE
50 West 50th Street
New York 20, New York

March 11, 1949

The Secretary
Federal Communications Commission
Washington 25, D. C.

Re: Public Notice 32161 (FIAR)

Dear Sir:

Reference is made to Public Notice 32161, in the matter of "A proposal for a revision of frequency provisions in the Inter-American Radio Agreement of Havana (1937) (Santiago, Chile Revision (1940)) E.A.S. 231, and the Frequency proposal of the United States at the forthcoming Fourth Inter-American Radio Conference (FIAR)."

* * * *

The geophysical frequency allocation in the 1,600 kc. to 1,700 kc. band is one of extreme importance to the petroleum industry. Because of considerations which are under way at the Federal Communications Commission at this time, I desire to bring to your attention, and, through you, to those on your staff who are working on frequency allocation problems, the necessity for retaining these frequencies or their equivalent for the continuation of geophysical work in oil exploration activities.

At the meeting of the American Petroleum Institute's Central Committee on Radio Facilities, in Chicago, November 7, 1948, the problem of retaining the geophysical frequencies in the 1,600 to 1,700 kc. band received considerable attention. We of the geophysical industry fully appreciate the great demand for these frequencies in other services and the serious allocation problem that arises from the need. On the other hand we wish to make perfectly clear that the need for continuance of the five low frequency geophysical channels which we have had since about 1928 arises not from a mere matter of preference but from sheer necessity based on long experience.

High frequencies made available for geophysical use have been widely adopted throughout the industry in those areas where reliable service may be obtained by their use. . . . However, it is the general experience of the industry that in some areas reliable radio has been possible only through the use of the 1,600–1,700 kc. channels. . . .

We realize that it is rather difficult to understand why these high frequency channels are not dependable in view of many reports to the contrary. The fact is, however, that it is not at all uncommon for example to find even the 30–40 mc. channels unreliable at distances of about one mile in the swamp areas of Louisiana. . . .

Similar failure of the high-frequency channels occurs in swamp areas involving heavy cypress cover. Likewise, in wooded areas which are commonly encountered, difficulty is even encountered on the 1,600–17,00 kc. channels due to abnormal attenuation of the very low power normally used in geophysical work. These experiences are not isolated examples, but represent common experience by all who are engaged in operations in these areas.

I should also mention such areas as West Texas where reliable operation was not possible at high frequencies when sand hills intervened. Refraction seismograph operations, which are of increasing importance in this area, are accomplished only by the use of the 1,600–1,700 kc. channels. A few exceptions may be found, but these are exceptions, whereas the geophysical industry cannot function except under conditions of 100% reliability.

* * * *

A refraction seismograph setup is very similar to the reflection setup as regards components and time-break transmission requirements. However, the important difference from the communications standpoint is the large distance which separates the shotpoint and the seismic dectector array.

* * * *

In particular, it should be noted that except in exceptional cases the use of high frequencies for the vital radio link is entirely impractical. Because of the distances involved and the fact that intervening terrain, wooded areas, or other obstructions are almost certain to be encountered, no one would attempt a refraction program unless the 1,600–1,700 kc. channels or their equivalent were available. In the case of ordinary communications between the usual type of commercial mobile units, the failure of the radio channel at any given time or in a particular local area may be of no serious consequence. In the case of a refraction program, it is not sufficient that operations be successful in a portion of the area, but *all* of the area must be amenable to exploration, otherwise the efficacy of the method as an exploration tool is completely lost.

It is no exaggeration to state that the loss of the low-frequency channels to the geophysical industry would mean, practically, the loss of refraction seismograph techniques in the petroleum exploration art. It should be added that while reflection methods are preferred for most purposes, there are many exploration problems that can be handled only by refraction methods. Moreover, there are areas, i.e., portions of West Texas, where reflection work is impossible and refraction techniques are the only solution.

* * * *

The material which I am submitting herewith has been furnished to me by Mr. R. D. Wyckoff who is Chairman of the Geophysical Radio Subcommittee of the American Petroleum Institute's Central Committee on Radio Facilities and who is also chairman of the Society of Exploration Geophysics Radio Facilities Committee. If you desire any additional information in connection with this matter, I shall indeed be pleased to supply it. I shall be grateful to you if you will advise us of the steps you will find it possible to take to reserve these frequencies for the continuation of geophysical work which has been going on in this part of the band for the past twenty years.

Very sincerely yours,
Joseph E. Keller

jek/A/hk

The Pennsylvania State College Division of Mineralogy and Petrology at State College, Pennsylvania, announces the presentation of a new graduate option and research in the field of sedimentology, electron microscopy, and experimental silicate petrography. Provisions are made for two full-time research assistantships and four half-time graduate assistantships during the coming academic year.

INTERNATIONAL GEOLOGICAL CONGRESS 18TH SESSION LONDON, AUGUST 25–SEPTEMBER 1, 1948

J. P. SCHUMACHER*
Houston, Texas

The 18th Session of the International Geological Congress was held in London between August 25 and September 1, 1948. The total registrations from approximately 77 countries numbered 1746.

The headquarters of the Congress was in the Geological Survey and Museum and the sessions were held in the Albert Hall, Imperial Institute and the Royal School of Mines.

The 389 technical papers presented were divided among 12 sections of which Section D, The Geological Results of Applied Geophysics, listed 27 papers.

A volume of titles and abstracts was presented to the members of the Congress, and the papers

* Official delegate of the Society of Exploration Geophysicists to the Congress.

will be published in a Report some time before August, 1952, at which time the next Session of the Congress will be held in Algeria.

J. Harlan Johnson has given a report on the organization, field trips and the council and committee meetings in the Bulletin of the A.A.P.G., Volume 32, Number 12, December 1948. Herewith are abstracts of the papers related to geophysics presented at the meeting.

ABSTRACTS

1. Gravity Prospecting for Lead and Zinc, New Mexico, by V. E. Barnes, R. W. Mathis and F. Romberg.

Observations of the relative force of gravity were made on the Houston-Thomas group of claims in the Pinos Altos Mountains, north of Silver City, New Mexico. The observed values of gravity were corrected for terrain effects, and the resulting map revealed two positive anomalies. The second of the U. S. Bureau of Mines diamond drill holes on one of the anomalies penetrated a lead-zinc ore body in which mining was started later. Two holes directed toward the second anomaly were not well located, missed ore, and no further drilling has been done.

An explanation is proposed for the systematic difference between the Bouger correction as computed from observed surface densities, and as computed from the graph of force versus elevation.

2. La Prospection Electrique Appliquee aux Recherches Hydrologiques dans la Presqu'ile de Dakar (A.O.F.) (Electrical Prospecting Applied to Hydrological Research in the Dakar Peninsula (French West Africa)), by J. J. Breusse.

Electrical sounding has made it possible to locate fresh water sands within salt water sediments. The thickness of the fresh water sands was also determined.

3. The Delineation of a Dyke by the Magnetic Method, by J. McG. Bruckshaw.

The Armathwaite Dyke in Cumberland was traced with geomagnetic methods over a distance of 16 miles. At the Penine fault the Dyke divides into a complex of smaller intrusions which can only be traced for short distances.

4. A Gravitational Survey over a Concealed Portion of the Warburton Fault, near Lymm, Cheshire, by W. Bullerwell.

A gravitational survey was made with a small double-beam Suss Torsion Balance over a conjectured fault line.

The gravitational field was found to be complex and a constant northerly regional gradient of considerable magnitude was revealed. Superimposed on the regional gradient a more local anomaly was indicated by a reduction and westerly swing in the gradient vectors. Further investigation of this local effect by both gradient and curvature values gave results which suggested that it was associated with a normal fault. Subtraction of the measured value of the Regional Gradient yielded maximum residual gradients showing linear continuity at small inclination to, and 100 yards to the southwest of, the conjectural line of the Warburton Fault, previously shown on the geological map.

5. Les Fosses Quaternaires d'Effondrement de Tunisie (Quaternary Troughs in Tunisia), by G. Castany.

Geological and geophysical surveys and drilling have revealed the presence of major trough faults in Tunisia. True "grabens" filled with recent sediments were found in the plains of Grombalia, and Kairouan. Borings have revealed 1300 to 1600 feet of Pliocene and Quarternary deposits.

These features show the influence of Pliocene subsidence which has continued during Quaternary times and which is ascribed to isostatic adjustment.

6. Applications des Methodes de Prospection Electriques a un Probleme Particulier en Tunisie: Les Seuils Hydrauliques (Application of Electrical Prospecting Methods to a Special Problem in Tunisia: Hydrologic Sills), by G. Castany.

Resistivity methods have revealed a system of fracture zones and Quaternary scarps which separate different lithological units. It was also possible to determine the hade of faults and folding in the substratum. This research has been confirmed by deep electrical soundings.

7. Carottage Electrique et Etude des Sondages Mecaniques (Electrical Well Logging and Study of Mechanical Borings), by G. Castany.

During the last two years the Director of Public Works in Tunisia has applied electrical well logging to all the borings made in its territory. By this method it has been possible to obtain stratigraphical and lithological sections and to make correlations between the drill holes.

8. Geological Results of Geophysical Prospecting in the Discovery of the Adendaalsrust Goldfields in the Orange Free State of the Union of South Africa, by A. Frost and O. Weiss.

A diamond drill hole was located on a gravity anomaly determined by torsion balance measurements. This hole intersected Witwatersrand Quartzites at 1,000 feet. Over 300 deep diamond drill holes have now been completed of the average depth of about 5,000 feet each, resulting in discoveries of gold-bearing conglomerates and carbon reefs with possibilities for the establishment of about eleven new important gold mines.

The possibilities and limitations of the geophysical prospecting methods are reviewed in the light of the geological results.

9. Constitution Geologique des Depressions Perialpines de la Saone et du Rhone, d'apres la Prospection Geophysique (The Geology of the Peri-Alpine Depressions of the Saone and the Rhone Basins, France, as shown by Geophysical Prospecting), by J. Goguel.

Gravimetric and telluric methods and 30 electrical sounding diagrams have been used to investigate the Miocene and Pliocene covered plains of the Saone and Rhone.

By these methods it has been possible to locate faults and subsidence grabens in which great thicknesses of Oligocene sediments have been accumulated, and to determine the facies variations which are characterized by brackish sediments in the south and by limestone and conglomerates in the north. It has also been possible to outline the shape of the coal basin in the Bas-Dauphine by gravimetric methods. Other anomalies suggest the presence of intrusions of dense material which are not shown at the surface. The location of the Tertiary basins shows that these basins were obstacles to the folding of the Jura and Sub-Alpine mountain chains as if the sediments lacked plasticity.

10. Application of Seismic Reflection Methods to Saltdome Structures, by O. Heermann.

Structural interpretations of saltdomes in the northwest German Permain salt basin have been based mainly upon the results of extensive potash mining in the interior of salt masses, and comparatively little upon the structure of the Mesozoic flanks and basins. The analysis of regional seismic reflection surveys has led to marked progress in the interpretation of the structure of salt intrusions, particularly in the northern saltdome area of increasing thickness of Cretaceous and Tertiary sediments.

The piercement type of salt plug, and its present size and shape, are not always the result of an evolution since the first stage of salt flowage and the main phases of salt movement indicated in the Upper Jurassic, Lower Cretaceous, and Senonian unconformities.

Anticlinal and synclinal types of salt structures are discussed. Tensional and compressional types of salt intrusions alternate in the history of the individual salt structures.

Seismic reflection investigations in the basins between the salt domes indicate the pre-Cretaceous and pre-Senonian stages of the evolution of the salt domes and their position within the Saxonian folding. Later movement of salt structures, recent alignment and shape of shallow salt plugs, are partly independent of basement salt structures.

11. The Application of the Airborne Magnetometer to the Search for Iron Ore Deposits and the Mapping of Geological Structures, by A. A. Logathev (U.S.S.R.).

12. Delimitation Geo-electrique du Premier Pipe de Kimberlite Decouert dans les Champs Diamantiferes due Kasai (Congo Belge) (Delineation by Geo-electrical Methods of the First Kimberlite Pipe Discovered in the Kasai Diamond Field, Belgian Congo), by I. de Magnee.

The Bakwanga and eastern Kasai alluvial plains produce about 75% of the world production of industrial diamonds. A geophysical prospecting party discovered in 1946 the presence of Kimberlite "yellow ground" covered by a thick sand layer. It concluded that this Kimberlite is the source of diamonds encountered in the surrounding aluvial deposits. The decomposed Kimberlite is surrounded by horizontal pre-Cambrian limestone beds. Electrical logging showed that these limestones

are characterized by higher resistivity than the yellow ground. The measurements showed an oval shaped zone of lower resistivity covering approximately 45 acres. This anomaly was interpreted to be an extension of a Kimberlite pipe. Subsequent drilling has confirmed that interpretation.

13. Supersonic Vibration Reflexion Experiments, by C. Mehes (Hungary).

14. On Potential-drop-ratio Measurements in Structural Investigations, by A. A. T. Metzger.

The influence of the thickness and character of overburden on the mean of P. D. R.-curves, measured along the same profile in opposite directions, is discussed. It is shown that the deviation of the field curves from the mean has a certain diagnostic value for the study of vertical or nearly vertical contacts. The method is illustrated by an example.

15. Quelques Exemples d'application de la Methode Tellurique (Some Examples of the Application of the Telluric Method), by L. Migaux.

The author discusses briefly the principles of the telluric method and stresses the advantages of this method over other methods. He shows that telluric maps often give clearer pictures of sedimentary structures than gravity maps. He compares telluric and gravimetric surveys made in Morocco and in Aquitaine in France.

16. Fractures et Zones de Choc dans les Alpes Nord-occidentales (Fracture and Seismic Zones in the Northwest Alps), by F. Montandon.

The two most violent seismic disturbances in the limestone areas in the Alps occurred at Nidwald (intensity IX ½) in 1901 and in the Wildhorn area (intensity IX) in 1946, two areas which are very disturbed by faulting. The author discusses the relation of the last mentioned earthquake with the Pennine nappes, which have a tendency to advance from the south southeast to the north northwest. In the vicinity of the Hercynian Aar massive where this tectonic movement is less pronounced, the violence of seismic shocks is increased, such as in Brigue (intensity IX ½) in 1755 and Viege (intensity X) in 1855.

17. Seismologie et Structure du Soubassement des Alpes (Seismology and Alpine Basement Structure), by N. Oulianoff.

In 1946 seismic disturbances were registered at Neuchatel, Bale, Zurich and Coire. These observations confirm the hypothesis of possible relations between the Hercynian granite masses of Mont-Blanc and Vosges and between the Aar and the Black Forest. These two north-south trending ancient mountain chains would be separated by a depression which was formed before the advent of the Alpine orogeny. Seismic analysis has, for the first time, confirmed the existence of deep seated structures with vertical planes.

18. Some Earth Resistance Measurements in Holderness, by L. S. Palmer and J. M. Hough.

Geophysical earth-resistance measurements have been made at 13 stations on a north-south traverse run in the Holderness plain in order to map the surface of the underlying chalk and to determine the total depths of glacial overburden. Besides the theoretical discussion a description of the apparatus and the field technique was given.

In an appendix, a mathematical basis for interpreting points of inflection and critical gradients of the experimental graphs, is outlined. The resulting formulae have been used in the present calculation in place of the empirical Gish-Rooney Law.

19. Geophysikalische Karten von Nordwestdeutschland (Geophysical Maps of Northwestern Germany), by H. Reich.

The area has been investigated by magnetic, gravimetric and refraction seismograph methods. The results have been plotted on three maps at a scale of 1:500,000. Magnetic anomalies are principally due to petrographic changes in the basement. Gravimetric anomalies are due, especially in the southern part of the map, to salt tectonics and to regional effects. Seismic investigation shows the relief of the pre-Tertiary basement. It shows, particularly in the northern part of the map, the salt domes and the elongated salt anticlines. It is possible to make a comparison between the tectonics of the sedimentary series (seismic and gravimetric) and the constitution of the crystalline basement (magnetic and gravimetric).

20. The Gravitational Anomalies of the East-European Platform and Their Relations to Geological Structure, by N. S. Schatsky. (U.S.S.R.)

21. Applications of Schlumberger Methods to the Investigation of Coal Seams Encountered in Bore-holes, by M. Schlumberger and J. L. Mathieu.

Three of the Schlumberger methods used in connection with drilling for oil, namely electrical logging, side wall coring and dipmeter surveys, have been successfully employed for the investigation of coal seams. This paper gives a brief review of the three methods involved and shows practical examples of their application to the coal problem. Electrical logging locates the coal seams encountered in the bore-holes. Side wall coring brings to the surface a sample of the formation located and a dipmeter survey measures the dip and the orientation of the coal seam.

22. Is the Basement Complex Involved in Appalachian Folding?, by H. W. Straley.

Gravitational and magnetic geophysical work, supported by modified pressure box experiments, lead to the tentative conclusions, that: (1) Most of the major anticlines in the Appalachians, west of the Blue Ridge fault, may not be caused by crystalline (basement) rocks. (2) Some of these same anticlines may be localized over thrust faults, in which the basement complex is not involved. (3) The Blue Ridge fault block (the easternmost in the Appalachian system of shingle blocks) may have acted as a plunger, slipping over the basement complex and folding the yielding sediments before it.

23. Recent Observations of Gravity in Wales and the Borders, by H. I. S. Thirlaway and A. H. Cook.

This paper discusses the results obtained on 600 stations made with a Graf gravity meter in the Welsh Borderland. The results are presented in Bouguer Anomalies. The positive anomaly of the mid-Wales plateau is greater than expected and coincides with a region of post-Cretaceous rejuvenation. The Malvern line divides the mid-Wales plateau maximum from a gravity trough near Worcester. The gravity field is explained by a series of north-south faults with a total downthrow of 8,000 to 10,000 feet. A slight increase of gravity was obtained over the Church Stretton disturbance. The pattern of the gravity field has a Caledonian trend.

24. Radioactivity Measurements as an Aid to Geological Mapping, by E. N. Tiratsoo.

25. Seismic Refraction Methods and Dam Site Exploration, by O. Vecchia.

Refraction seismic methods were used to locate proposed dam sites. The work was carried on under varied conditions, including marshy ground and over a lake 130 feet deep. Depths to bedrock, thickness of glacial and of lake bottom sediments were determined and this information was valuable in the location and planning of the dam.

26. Some Geophysical Experiences in Water Supply, by R. C. S. Walters.

This paper describes four examples of geophysical prophecies confirmed subsequently by geological data. The resistivity method was used for a location of a dam site in Leicestershire and for hydrological investigations in the Chalks of Kent and in the limestone area of Lincolnshire.

27. Geological results of Geophysical Prospecting for Water on the New Goldfields in the Orange Free State of the Union of South Africa, by Weiss and A. Frost.

Electrical and magnetic measurements were carried out for the location of dykes and the selection of shallow water bore holes.

Besides the geophysical papers listed in Section D the following papers read in other sections are of some geophysical interest.

28. A Geochemical Method of Prospecting for Ore Deposits, by S. Miholic.

The method is based on radioactive transformation of rubidium into strontium. The method was applied with success in 1940 while prospecting for copper in northwestern Croatia.

29. Air Survey and Geology, by T. D. Weatherhead.

Besides other methods of air surveys the application of aerial photography to aerial magnetometer surveys is discussed.

30. Problemes de Tectonique Profonde en Mediterranee Occidentale (Deep Seated Tectonic Problems in Western Mediterranean), by H. de Cizancourt.

Gravimetric Bouguer data have been compiled on a map which covers the western Mediterranean and adjacent countries. The interpretation of the positive and negative anomalies has been made with a new method which is different from the Pratt and Airy hypotheses. It shows that the

Mediterranean Basin is practically in isostatic equilibrium. The relations of the different Alpine chains are discussed and the existence of a series of deep seated folds is shown for the first time.

31. Geological-geophysical-geochemical Significance of Geosynclines, by R. M. Field.

To be briefed by the case method illustrating the significance of: (1) Evolution of the international concept of geosynclines from 1880 to 1948; (2) interrelation of paleontological, stratigraphical, dynamical, structural, geomorphological and geophysical techniques.

Among several case illustrations the author discusses: Marine geophysics of island acrcs and submerged continental margins. East Indies, West Indies, east coast of North America.

32. Nordsee and Nordmeer als Aussichtsreichstes gebiet fuer Geologisch-geophysikalische Meeresforschung (North Sea and North Atlantic as a Favorable Area for Geological and Geophysical Oceanic Research), by R. Schwinner.

Magnetic and gravimetric methods can be used to determine the relief of the ocean floor and the relations between the mountain ranges of Scotland and Norway.

33. Geologie et Activite Sismique en Turquie (Presentation de la Nouvelle Carte Sismologique de la Turquie) (Geology and Seismic Activity in Turkey (Presentation of a New Seismological Map of Turkey)) by E. Lahn.

The five principal seismic zones are determined by fairly recent cratogenic conditions and do not correspond with the orogenic structural trends.

34. Tremblements de Terre de l'Antolie Septentrionale, (Earthquakes in Northern Anatolia), by H. N. Pamir.

UPPER PENINSULA OF MICHIGAN MINERAL INDUSTRIES CONFERENCE ON RADIOACTIVE ORES

HELD AT
THE MICHIGAN COLLEGE OF MINING AND TECHNOLOGY
HOUGHTON, MICHIGAN
MAY 6, 1949

Purpose: To help coordinate and make more effective the search for radioactive ores in Upper Michigan, Wisconsin, and Minnesota.

The technical papers presented at the conference were as follows:

"Domestic Uranium Program of the United States Atomic Energy Commission," by Mrs. Muriel Mathez, Chief, Mineralogical Laboratories, Raw Materials Operations, U. S. Atomic Energy Commission.

Mrs. Mathez pointed out the need for additional supplies of uranium ore if we are to maintain our world leadership in atomic energy, and described in detail the efforts of the Atomic Energy Commission aimed at supplying this need. Low grade ore deposits in which uranium might be a valuable by-product were discussed, as well as high-grade deposits which would serve the immediate needs. The economic aspects of uranium prospecting and mining were discussed at length.

"Pitchblende—the Primary Source of Uranium," by Dr. Phillip L. Merritt, Assistant Manager, Raw Materials Operations, U. S. Atomic Energy Commission.

Mr. Merritt reviewed the history of uranium production, pointing out that the discovery of uranium ores had been the result of exploration for more commercially interesting minerals, and emphasizing that today's need for uranium cannot be met except by a direct and intensive search.

The geology and productivity of the world's major deposits of uranium ore were reviewed, with special emphasis on the Joachimsthal in the Erzgebirge Region of Saxony and Bohemia, the Eldorado of Great Bear Lake, Canada, and the Shinkolobwe in the Belgian Congo.

"The Geologic Environment of Primary Vein Deposits of Uranium," by Donald L. Everhart, Exploration Staff, U. S. Atomic Energy Commission.

Mr. Everhart presented a thorough study of the conditions of deposition and paragenesis of primary vein deposits of uranium, with emphasis on the usual mesothermal conditions and the typical zoning. Some aspects of the sources of the hydrothermal solutions were considered and the relationship of the veins to the plutons were described. In conclusion, guides for uranium ores were given, based on the relationship as outlined earlier. These guides included geologic, mineralogic, and chemical clues which could be used in systematic prospecting.

"Canadian Uranium Deposits with Emphasis on the Theano Point, Ontario Discoveries," by Dr. A. H. Lang, Geological Survey of Canada.

Dr. Lang reviewed briefly the history of uranium prospecting and discoveries in Canada, using maps and photographs to clarify the salient features of the areas involved. One of the important aspects of Canadian uranium prospecting was the fact that almost all of the important discoveries were in the border zone of the Canadian Shield. Recent finds at Theano Point, Ontario, were discussed in detail with emphasis on the general geology, the occurrence of the veins, and the prospects of future exploration.

"Geiger Counter Reconnaissance in Upper Michigan, 1948," by C. Ernest Kemp, Geology Department, Sault Ste. Marie Branch, Michigan College of Mining and Technology.

Mr. Kemp presented data gathered during the summer of 1948 by means of the Geiger counter in a number of areas in the Upper Peninsula of Michigan. While no uranium concentrations of importance were found, many differences in the radioactive properties of the rocks and minerals were noted. These data may be of value in further prospecting for uranium, and may also prove valuable in stratigraphic studies. Mr. Kemp used the Geiger counter on outcrops and also conducted surveys underground in some of the iron mines.

A demonstration of portable Geiger counters was arranged by Mr. F. W. Stead, Instrumentation Specialist for the U. S. Geological Survey. Also, Mr. Stead gave a discussion of the theoretical aspects of radioactivity studies with emphasis on Geiger counter theory and application. Many aspects of empirical prospecting techniques by means of the counter were covered in detail.

In addition to the technical papers, an inspection trip was arranged through the new Radiations Laboratory of the Metallurgy Department, Michigan College of Mining and Technology.

Approximately 200 people, largely from areas in the Great Lakes Region, attended the conference.

W. A. LONGACRE

PATENTS*

4—ACCELEROMETER

U. S. No. 2,458,016. M. Morrison. Iss. 1/4/49. App. 1/22/44.

Integrating Accelerometer. An aircraft speedometer in which an acceleration indication is obtained by the deflection of a spring by an inertia mass and a time integral obtained by having the deflection control the gear ratio between a constant-speed motor and the speed indicator.

12—ACOUSTIC MEASUREMENTS

U. S. No. 2,458,164. D. C. Hill and W. A. McGlashen. Iss. 1/4/49. App. 10/25/43.

Gravitometer. A device for determining the density of a gas by passing it into a whistle having a constant frequency resonator and indicator connected to it, the length of the whistle tube being observed for maximum response of the resonator.

U. S. No. 2,458,771. F. A. Firestone. Iss. 1/11/49. App. 3/15/43. Assign. The Regents of the University of Michigan.

Supersonic Reflectoscope. A sonic flaw detector in which reflections are indicated as deflections of a c-r tube trace which executes a series of horizontal sweeps representing a series of vertical regions in the material under test, the horizontal sweeps and their separation on the screen being controlled by a series of multivibrators.

U. S. No. 2,459,162. H. C. Hayes. Iss. 1/18/49. App. 11/16/40.

Acoustical Sound Locating Device. A device for determining the azimuthal direction of a sound having a rotating mirror which projects the sound axially into a microphone from which it is amplified and indicated by a synchronously rotating indicator.

U. S. No. 2,463,642. R. K. Potter. Iss. 3/8/49. Appl. 12/4/46. Assign. Bell Telephone Laboratories, Inc.

Wave Analysis. A method of analyzing a wave by recording it on an endless tape, selecting various frequencies which are compared with a synchronous saw-tooth wave and the phase of equal intensity recorded so as to obtain an intensity-frequency chart of the wave.

U. S. No. 2,465,355. G. W. Cook. Iss. 3/29/49. App. 1/27/43 and 2/14/45.

Wave Analyzer. A wave analyzer in which the wave is applied to a number of filters in parallel whose outputs are scanned by a cyclically-operated electronic switch and the intensity-frequency analysis indicated on a c-r tube screen.

16—AIRPLANE FLIGHT INSTRUMENTS

U. S. No. 2,458,016. M. Morrison. Iss. 1/4/49. App. 1/22/44.

Integrating Accelerometer. An aircraft speedometer in which an acceleration indication is obtained by the deflection of a spring by an inertia mass and a time integral obtained by having the deflection control the gear ratio between a constant-speed motor and the speed indicator.

U. S. No. 2,458,022. J. O. Phelps and G. W. Cottrill. Iss. 1/4/49. App. 8/9/44. Assign. Airpath Instrument Co.

Altimeter. An aneroid altimeter having a flight level indicator and which may be set for direction and barometric pressure.

* Abstracts by O. F. Ritzmann, Gulf Oil Corporation.

U. S. No. 2,458,331. G. L. Borell. Iss. 1/4/49. App. 4/25/45. Assign. Minneapolis-Honeywell Regulator Co.

Flowmeter. A hot-wire flow meter or rate-of-climb meter which is corrected for density of the air by having a by-pass with a valve controlled by an aneroid.

U. S. No. 2,459,074. H. W. Hastings-Hodgskins. Iss. 1/11/49. App. 7/3/42 and 5/1/43. Assign. Radio Corp. of America.

Course and Height Indicator for Aircraft. A combined radio altimeter and ground speed and course indicator having a rotating antenna which transmits a variable frequency rotating beam toward the ground and a receiver which picks up the reflections whose beat with the transmitted signal is indicated on a synchronously rotating c-r tube trace.

U. S. No. 2,461,521. M. L. Clopton. Iss. 2/15/49. App. 9/19/47.

Sensitive Element for Space Speed, Track and Angle of Attack Indicators. A gyro mounted in three gimbal rings with mutually perpendicular axes and a weight on the inner gimbal ring at one end of the gyro axis.

U. S. No. 2,461,533. R. G. Dosé. Iss. 2/15/49. Appl. 2/4/46.

Automatic Skid Corrector. A device for automatically keeping an airplane in trim and having a mercury globule in a tube with contacts at each end controlling a reversible motor which adjusts the trim tabs.

U. S. No. 2,465,411. H. P. Williams. Iss. 3/29/49. App. 6/27/44 and 7/7/45. Assign. International Standard Electric Corp.

Radio Navigational System. A combined glide-path and approach-path indicating system in which course-indicating radio waves are radiated from ground transmitters and indicated on a c-r tube in the plane as crossed lines similar to a crossed-pointer indicator.

U. S. No. 2,465,723. D. M. Heller. Iss. 3/29/49. App. 5/6/42 and 5/6/43. Assign. The General Electric Co., Ltd.

Radio Wave Altimeter. A radio altimeter having a radiating antenna connected in an impedance bridge which is balanced when the plane is at a high altitude and whose unbalance at low altitude is indicated.

U. S. No. 2,465,775. M. C. White. Iss. 3/29/49. App. 8/10/45.

Altimeter. An altimeter having a motor-driven constant-speed air screw which produces a stream of air impinging on a second air screw whose torque is indicated.

U. S. No. 2,465,957. C. Dienstbach. Iss. 3/29/49. App. 9/22/45. Assign. Dienstbach Ground Speed Indicator, Inc.

Scanning Mirror Navigational Instrument for Automatically Affording Direct Indications of the Ground Speed and Drift of Aerial Vehicles. A ground-speed indicator having a variable-speed motor which by means of a cam repeatedly rotates a mirror so as to sweep the ground below the plane, the motor speed being indicated when the image of the ground appears to stand still and an altitude correction made on a chart.

48—CASING PERFORATOR

U. S. No. 2,462,784. A. L. Smith. Iss. 2/22/49. App. 11/17/41. Assign. Lane-Wells Co.

Well Perforating Gun. A casing perforator having an axial powder chamber and opposed transverse gun bores with bullets joined back to back, the powder chamber being connected to a groove

at the joint between bullets with rupture of the joint taking place when pressure is built up with the bullets fired in opposite directions.

68—COMPUTING DEVICES

U. S. No. 2,458,697. E. R. Fenske. Iss. 1/11/49. App. 11/10/47. Assign. Universal Oil Products Co.

Electrical Computer. A transposition circuit for a simultaneous equation computer to permit the computer to accommodate additional equations.

U. S. No. 2,459,106. A. C. Hardy and E. C. Dench. Iss. 1/11/49. App. 8/6/46. Assign. Interchemical Corp.

Computing Apparatus. An electronic simultaneous equation solver having a circuit for simulating the constant terms and computing circuits for simulating the operations on the unknowns and a subtraction circuit connected between them and to an amplifier which automatically controls one of the unknowns.

U. S. No. 2,461,738. W. C. Johnson. Iss. 2/15/49. App. 6/10/46.

Device for Solving Equations. An impedance network which may be used for solving a non-linear differential equation such as the equation of heat flow in cylindrical coordinates.

U. S. No. 2,461,895. A. C. Hardy and E. C. Dench. Iss. 2/15/49. App. 7/8/44 and 12/3/46. Assign. Interchemical Corp.

Multiplying Apparatus. An electronic multiplying device in which square waves of irrationally related frequencies and whose respective fractional pulse lengths represent the factors to be multiplied are fed into an indicator which produces a signal in proportion to the time during which pulses occur simultaneously.

U. S. No. 2,463,553. R. C. Olesen. Iss. 3/8/49. App. 4/5/44. Assign. Consolidated Engineering Corp.

Integrating System. An electronic integrating amplifier using a network of condensers and resistors in the output circuit with a tap for an inverse-feedback connection.

U. S. No. 2,463,788. G. M. McGuckin. Iss. 3/8/49. App. 12/10/46. Assign. Socony-Vacuum Oil Co., Inc.

Apparatus for Solution of Snell's Law. A mechanical device with an articulated system of graduated scales for computing problems based on Snell's law.

U. S. No. 2,463,789. G. M. McGuckin. Iss. 3/8/49. App. 12/10/46. Assign. Socony-Vacuum Oil Co., Inc.

Refracted Ray Calculating Device. A mechanical device with a graduated arm and a graduated circle for computing problems based on Snell's law.

88—CORE TESTING

U. S. No. 2,458,093. M. Muskat and N. D. Coggeshall. Iss. 1/4/49. App. 2/19/45. Assign. Gulf Research & Development Co.

Method of Determining the Fluid Content of Well Cores. A method of determining drilling fluid invasion of a core by adding to the mud a soluble artificially radioactivated material before cutting the core, then cutting the core and measuring its radioactivity.

U. S. No. 2,465,948. H. J. Welge. Iss. 3/29/49. App. 8/20/46. Assign. Standard Oil Development Co.

Core Porosity Analysis and Apparatus Therefor. An apparatus for determining the retentivity of a core sample for a fluid by confining a saturated sample on one side of a porous disc which preferen-

tially passes the fluid and forcing into the sample an immiscible fluid until a predetermined pressure is built up and measuring the amount of fluid displaced from the sample.

108—ECHO SOUNDING

U. S. No. 2,458,415. R. E. Peterson. Iss. 1/4/49. App. 8/19/42 and 10/22/47. Assign. Submarine Signal Co.

Apparatus for Echo Distance Measurement. An echo sounding apparatus using a single projector for sending and receiving and a rotating indicating dial with cams on the same shaft for connecting the projector to the transmitting oscillator and receiving amplifier at proper time sequence.

U. S. No. 2,460,316. H. M. Trent and T. F. Jones. Iss. 2/1/49. App. 7/31/44.

Echo Ranging and Listening Gear. An echo-sounding apparatus which transmits a number of short pulses in succession with the time spacing adjustable so that transmission will coincide with reception of reflection of the previous pulses.

U. S. No. 2,463,328. D. O. Sproule. Iss. 3/1/49. App. 6/9/44 and 7/6/45. Assign. Henry Hughes & Son Ltd.

System of Wave Trains. An echo sounding or flaw detecting system in which a short wave train of increasing frequency is transmitted and the received wave sharpened into a pulse by transmitting it over a dispersive medium of proper length so that the high frequencies catch up to the low frequencies.

116—ELECTRIC LOGGING

U. S. No. 2,459,196. W. H. Stewart. Iss. 1/18/49. App. 12/22/38. Assign. Sun Oil Co.

Electrical Logging Method and Apparatus. A system for electrically logging through casing by passing a current from the casing to a remote point and running four longitudinally-spaced casing contactors into the well, the end contactors being connected to a battery and ammeter and the center ones to a galvanometer and observing the current required to reduce the galvanometer indication to zero.

124—ELECTRICAL PROSPECTING

U. S. No. 2,460,095. A. Love. Iss. 1/25/49. App. 5/22/44 and 11/22/44.

Instrument for Measuring Resistances. A resistance measuring apparatus having a hand-cranked a-c generator shunted by a condenser and resistance to give an output voltage independent of speed and supplying current through a rectifier and a milliammeter to the resistance being tested.

U. S. No. 2,461,111. M. L. Flinspach and J. H. Flinspach. Iss. 2/8/49. App. 8/16/46.

Soil Moisture Indicator. A device having two insulated electrodes with metal tips which are driven into the ground a standard depth and connected to an ohmmeter circuit with an adjustable resistor for compensating for various electrode spacing.

132—ELECTROMAGNETIC PROSPECTING

U. S. No. 2,463,252. H. G. Doll. Iss. 3/1/49. App. 3/8/46. Assign. Schlumberger Well Surveying Corp.

Frequency Stabilization of Alternating Current Networks. An a-c mutual impedance bridge which may be balanced for more than one frequency by introducing into the output two components of a first phase which are proportional to two different powers of the frequency and two components of a second phase which are proportional to two different powers of the frequency.

136—EXPLOSIVE

U. S. No. 2,463,709. D. M. McFarland. Iss. 3/8/49. App. 11/16/43. Assign. Atlas Powder Co.

Ammonium Nitrate Explosive. An explosive assembly having an outer water-pervious shell containing a water-absorptive ammonium nitrate with sensitizer composition and a center core of a water-proof dynamite.

U. S. No. 2,465,467. J. B. Morton. Iss. 3/29/49. App. 6/11/46. Assign. Hercules Powder Co.

Electric Blasting Cap. A safety-type electric blasting cap having lead azide in the upper portion of the priming charge.

140—FLAW DETECTOR

U. S. No. Re. 23,090. (Orig. No. 2,439,131.) F. A. Firestone. Iss. 3/15/49. App. 11/20/43, 4/6/48 and 10/18/48. Assign. United Aircraft Corp.

Resonance Inspection Method. A method of measuring the wall thickness of a hollow airplane propeller by applying a piezoelectric crystal excited with successive pulses of varying frequency and observing the frequency of the resonant standing waves after the end of each pulse.

U. S. No. 2,458,581. F. A. Firestone and J. R. Frederick. Iss. 1/11/49. App. 5/21/46. Assign. Sperry Products, Inc.

Supersonic Inspection. A coupling between the crystal and the test material in a sonic inspection system using a piece of metal foil interposed between the crystal and the material with a thin liquid film between the foil and the crystal and also between the foil and the test material.

U. S. No. 2,458,771. F. A. Firestone. Iss. 1/11/49. App. 3/15/43. Assign. The Regents of the University of Michigan.

Supersonic Reflectoscope. A sonic flaw detector in which reflections are indicated as deflections of a c-r tube trace which executes a series of horizontal sweeps representing a series of vertical regions in the material under test, the horizontal sweeps and their separation on the screen being controlled by a series of multivibrators.

U. S. No. 2,460,153. R. Smoluchowski. Iss. 1/25/49. App. 7/30/46. Assign. General Electric Co.

Piezoelectric Crystal Holder. A device for holding the crystal against the surface of the test material in a sonic inspection system and having a spring which presses the crystal against the test surface and adjusting screws which tilt the crystal at the proper contact angle.

U. S. No. 2,461,252. W. C. Barnes and H. W. Keevil. Iss. 2/8/49. App. 6/5/44.

Method and Apparatus for Detecting Flaws. A flaw detector for testing rails in which the rail is longitudinally magnetized and in which the pickup unit has two contiguous cores whose coils are connected in series opposition to a peak-detecting amplifier.

U. S. No. 2,461,253. W. C. Barnes and H. W. Keevil. Iss. 2/8/49. App. 6/5/44.

Flaw Detection Apparatus. A flaw detector for testing rails from a moving car and having a magnetizing magnet mounted with one pole close to the rail and followed by a pickup unit connected to an amplifier which is sensitive to sharp peaks of one direction.

U. S. No. 2,461,494. T. de Forest. Iss. 2/8/49. App. 5/7/45. Assign. R. C. Switzer and J. L. Switzer.

Method and Composition for Flaw Detection. A fluid for a "wet" magnetic testing method which has ferromagnetic particles suspended in a liquid with an insoluble fluorescent substance adhering to the magnetic particles and a non-fluorescing organic dye dissolved in the liquid to quench any fluorescence of the liquid.

U. S. No. 2,461,543. R. Gunn. Iss. 2/15/49. App. 2/1/41.

Apparatus and Method for Studying Wave Propagation. A sonic testing method in which the object is put under tension and the transmission attenuation of an impulse observed on a c-r tube.

U. S. No. 2,461,984. C. G. Kaehms. Iss. 2/15/49. App. 5/15/45. Assign. Southern Pacific Co.

Flaw Detector Mounting and Control. A carriage for a rail flaw detector on a test car which has a guide wheel held against the gauge side of the rail by a linkage from a piston in a hydraulic cylinder.

U. S. No. 2,463,297. M. Muskat and N. D. Coggeshall. Iss. 3/1/49. App. 12/21/44. Assign. Gulf Research & Development Co.

Apparatus for Testing Insulating Materials. An apparatus for detecting conducting inclusions in insulating tubing and having a microwave transmitter and opposing reflector inside the tube and a conducting tube and detector outside the tube.

U. S. No. 2,463,328. D. O. Sproule. Iss. 3/1/49. App. 6/9/44 and 7/6/45. Assign. Henry Hughes & Son Ltd.

System of Wave Trains. An echo sounding or flaw detecting system in which a short wave train of increasing frequency is transmitted and the received wave sharpened into a pulse by transmitting it over a dispersive medium of proper length so that the high frequencies catch up to the low frequencies.

148—FLOW METER

U. S. No. 2,458,331. G. L. Borell. Iss. 1/4/49. App. 4/25/45. Assign. Minneapolis-Honeywell Regulator Co.

Flowmeter. A hot-wire flow meter or rate-of-climb meter which is corrected for density of the air by having a by-pass with a valve controlled by an aneroid.

U. S. No. 2,458,637. R. H. Pratt and J. Q. Underwood, Jr. Iss. 1/11/49. App. 4/5/46. Assign. Celanese Corp. of America.

Fluid Flow Measuring Device. A rotameter for measuring flow of liquids containing suspended matter having a central guide rod carrying a sliding weight and a frusto-conical float which can wobble as it rotates so as to keep it free of solids.

U. S. No. 2,459,689. P. S. Dickey and J. F. Shannon. Iss. 1/18/49. App. 9/22/44. Assign. Bailey Meter Co.

Fluid Rate of Flow Measuring Apparatus. A fluid flow meter having a sliding plug valve on a long spring and in which the flow causes the plug to uncover slotted ports, motion of the plug being transmitted to an armature inside coils of an electro-magnetic bridge.

U. S. No. 2,461,351. L. Silverman. Iss. 2/8/49. App. 11/21/45.

Flowmeter. A flowmeter having a cylindrical flow tube which is cut off at an acute angle and the opening covered by a counterbalanced vane whose deflection is observed.

U. S. No. 2,463,473. W. M. Boothby. Iss. 3/1/49. App. 7/7/45.

Flowmeter. A gas flow meter having a porous medium through which the gas flows and arranged so that a member of parallel areas may be opened for flow to change the calibration and with a differential pressure gauge across the medium.

160—GALVANOMETER

U. S. No. 2,463,785. H. R. Lubcke. Iss. 3/8/49. App. 11/23/45. Assign. Thomas S. Lee Enterprises, Inc.

Electromechanical Device. A scanning galvanometer with two degrees of freedom having the mirror mounted in gimbals with the inner and outer gimbal rings wound with current coils.

U. S. No. 2,465,082. K. R. Geiser. Iss. 3/22/49. App. 8/2/44. Assign. General Electric Co.

Electronic Amplifier for Galvanometer Oscillographs. A method of galvanometric recording in which the galvanometer is deflected by high-frequency unidirectional pulses whose amplitude is modulated by amplification in response to the signal to be recorded.

172—GEOCHEMICAL PROSPECTING

U. S. No. 2,459,512. R. H. Fash and J. G. Campbell. Iss. 1/18/49. App. 11/6/44. Assign. Ralph H. Fash, Trustee.

Petroleum Exploration by Soil Analysis. A method of soil analysis in which samples are extracted with an oil solvent and non-petroleum substances removed from the extract by contact with a preferential absorbent and the fluorescence of the remainder measured.

U. S. No. 2,465,563. A. J. Abrams. Iss. 3/29/49. App. 6/13/40. Assign. Socony-Vacuum Oil Co., Inc.

Geophysical Prospecting Method. A method of soil gas prospecting in which holes are drilled to below the water table or atmospheric breathing zone and a portion of the hole isolated and the rate of evolution of gas from the surrounding soil measured.

U. S. No. 2,465,564. A. J. Abrams. Iss. 3/29/49. App. 11/4/43. Assign. Socony-Vacuum Oil Co., Inc.

Location of Buried Hydrocarbon Deposits. A method of soil gas prospecting in which holes are drilled to below the limit of atmospheric breathing and a portion of the hole isolated and the rate of evolution of various constituent gases measured by means of selective absorption materials.

188—HYGROMETER

U. S. No. 2,458,348. H. W. Cleveland. Iss. 1/4/49. App. 5/6/44. Assign. Eastman Kodak Co.

Electric Resistance Film Hygrometer. An electric hygrometer using the change in resistance of a gelatin film or a film of gelatin impregnated with a hygroscopic electrolyte.

U. S. No. 2,459,810. O. L. Graves and R. Bishop. Iss. 1/25/49. App. 3/31/45.

Dew-Point Indicator. An automatic dew-point indicator having a thin electric heating element between a cold cell and a mirror, with the mirror reflecting light to a photocell whose output is amplified and fed to the heater and the mirror temperature indicated by a thermocouple.

U. S. No. 2,460,065–074. P. B. Davis. Iss. 1/25/49. App. 2/7/45. Assign. The Davison Chemical Corp.

Relative Humidity Indicators. A number of chemical relative-humidity indicators which are color-sensitive and comprising various amounts of cobalt sulfate, copper bromide, cobalt bromide, cobalt phosphate, cobalt chloride, copper chloride, cobalt iodide or cobalt thiocyanate.

U. S. No. 2,461,310. P. Cilley. Iss. 2/8/49. App. 5/21/47. Assign. The Foxboro Co.

Apparatus for Measuring Humidity. An electric hygrometer having a hygroscopic sheet of material which expands and contracts with changes of humidity and a filament-type strain gauge bonded to the sheet and connected in a Wheatstone bridge indicating circuit.

U. S. No. 2,464,546. J. C. Albright. Iss. 3/15/49. App. 6/20/45. Assign. The Davison Chemical Co.

Humidity Analyzer. Apparatus for determining the dew-point temperature of a gas having a series of thermometers extending into a series of illuminated cooled chambers through which the gas flows.

192—INCLINOMETER

U. S. No. 2,457,826. G. L. Kothny. Iss. 1/4/49. App. 7/22/43 and 2/19/47. Assign. Sperry-Sun Well Surveying Co.

Well Surveying Device. An electrolytically-recording pendulum inclinometer having in the recording circuit a conducting fluid which drains through an orifice and shuts off the recording current after a time and also having the pendulum instrument suspended on a spring below the timer.

196—INFRARED MEASUREMENTS

U. S. No. 2,462,946. N. D. Coggeshall and M. Muskat. Iss. 3/1/49. App. 4/11/47. Assign. Gulf Research & Development Co.

Automatic System of Process Control by Infrared Spectrometry. A process control system in which the product is analyzed by making infrared absorption measurements at several wave lengths by adjusting the monochromator in succession to these wave lengths and translating the results into component concentrations.

U. S. No. 2,462,995. O. F. Ritzmann. Iss. 3/1/49. App. 4/11/47. Assign. Gulf Oil Corp.

Process Control System. A process control system in which the product is analyzed by making infrared absorption measurements in several spectrometers each adjusted to a different wave length and the concentrations determined from logarithmic potentiometers.

200—LEVEL INDICATORS

U. S. No. 2,457,874. A. H. Davis, Jr. Iss. 1/4/49. App. 12/20/43. Assign. American Machine and Metals, Inc.

Fluid Level Indicator. A device for detecting the level of suds or froth in a tank by sucking air from the tank at the required level and detecting presence of froth by increased flow resistance which lowers the pressure in the suction pipe.

U. S. No. 2,460,503. W. H. Howe. Iss. 2/1/49. App. 2/26/45. Assign. The Foxboro Co.

Apparatus for Measuring Liquid Level or Specific Gravity. A liquid level or specific gravity indicator having respectively a floating or submerged float whose apparent weight bends a supporting bar having a filament-type strain gauge whose resistance change is indicated.

216—MAGNETIC COMPASS

U. S. No. 2,464,057. H. W. Phair. Iss. 3/8/49. App. 11/23/44. Assign. Fairchild Camera and Instrument Corp.

Earth Inductor Compass. An earth inductor compass in which auxiliary a-c signals are generated by auxiliary a-c generators on the same shaft as the rotating inductor and the auxiliary a-c combined with the inductor output to compensate for extraneous permanent stray fields.

224—MAGNETIC RECORDER

U. S. No. 2,458,315. D. E. Sunstein. Iss. 1/4/49. App. 5/3/45. Assign. Philco Corp.

Method and Apparatus for Reproduction of Angular Magnetic Recordings. A pickup system for a wire recorder in which two pickup coils are arranged about the wire 90° apart and each feed balanced modulators which are energized 90° apart, the modulator output voltages being added and demodulated.

U. S. No. 2,459,299. W. P. West. Iss. 1/18/49. App. 7/20/46. Assign. Philco Corp.

Magnetic Transducer with Separable Pole Faces. A magnetic-recorder pole piece made by winding

insulated magnetic sheet on a mandrel and cutting C-shaped pieces which surround a non-magnetic support with the entire unit placed between the poles of a magnet yoke.

U. S. No. 2,460,190. M. O. Petroff and W. F. Straub. Iss. 1/25/49. App. 3/21/46. Assign. Charles P. Peirce.

Wire Recorder Indicator. A magnetic recorder indicator having a lead screw with half-nuts which carry pointers and operate switches at preset points.

U. S. No. 2,461,368. W. E. Bradley. Iss. 2/8/49. App. 12/19/44. Assign. Philco Corp.

Magnetic Transducing Apparatus Utilizing a Helical Sound Trace. A system for transverse magnetic recording in the form of a helical trace on a round wire in which the signal modulates a carrier which is amplified and recorded by two quadrature pairs of pole pieces with a slight displacement along the wire, the modulated carrier to one pair being delayed in phase.

U. S. No. 2,463,001. T. M. Shrader. Iss. 3/1/49. App. 5/30/45. Assign. Radio Corp. of America.

Telegraphone. A cartridge for handling a magnetic recording wire having a storage reel and a take-up reel side by side with the wire going from one reel to the other over a grooved guide piece to which the recording-reproducing head may be attached.

232—MAGNETOMETER

U. S. No. 2,461,864. T. Zuschlag. Iss. 2/15/49. App. 12/13/45. Assign. Hans T. F. Lundberg.

Instrument for Geophysical Exploration. A magnetometer having two compass needles independently suspended in casings having an axial separation so that interaction occurs betwen the needles, the spread angle between the needles being observed.

236—MASS SPECTROMETRY

U. S. No. 2,462,190. J. A. Hipple, Jr. and D. J. Grove. Iss. 2/22/49. App. 3/15/45. Assign. Westinghouse Electric Corp.

Amplifier for Small Direct Currents. An amplifier using an electrometer input tube and having an inverse feed-back circuit giving an amplification of unity and operated at an input grid bias giving zero grid current.

U. S. No. 2,463,239. J. R. Bowman and F. F. Versaw. Iss. 3/1/49. App. 2/19/45. Assign. Gulf Research & Development Co.

Apparatus for Producing Minute Orifices. A device for making a minute orifice through which gas samples may be introduced into a mass spectrometer by making a small hole in a gold disc and peening the disc on an anvil so that impact forces are transmitted to the disc with radial symmetry surrounding the hole.

U. S. No. 2,463,544. R. V. Langmuir. Iss. 3/8/49. App. 4/30/43 and 10/7/46. Assign. Consolidated Engineering Corp.

Mass Spectrometry. A mass spectrometer in which high recording speed is attained by having an a-c source in series with the d-c anode voltage of the electron gun so that a modulated electron stream is obtained and passing the resulting modulated ion current signal through a narrow band-pass filter.

U. S. No. 2,463,545. R. V. Langmuir. Iss. 3/8/49. App. 4/30/43 and 10/7/46. Assign. Consolidated Engineering Corp.

Mass Spectrometry. A mass spectrometer in which high recording speed is attained by having an a-c source in series with a d-c source to supply filament current so that a modulated electron stream is obtained and passing the resulting modulated ion current signal through a narrow band-pass filter.

240—MECHANICAL LOGGING

U. S. No. 2,459,499. J. H. Castel. Iss. 1/18/49. App. 12/17/43. Assign. Schlumberger Well Surveying Corp.

Casing Joint Locator. Apparatus for locating the annular recess at casing collars and having a finger urged outward by a spring and arranged to open an electrical contact when it drops into a recess and indicating at the surface.

276—PERMEABILITY TESTING

U. S. No. 2,460,655. E. W. Rickmeyer. Iss. 2/1/49. App. 11/16/45. Assign. Jefferson Electric Co.

Apparatus for Determining the Permeability of Materials. A device for timing the passage of gas through a porous sintered metal time-delay element of a mercury switch by observing the fall of mercury in a U-tube pressure gauge with contacts to control an electric clock.

U. S. No. 2,462,014. H. J. Welge. Iss. 2/15/49. App. 8/23/46. Assign. Standard Oil Development Co.

Micropermeameter for Measuring the Permeability of Oil Field Cuttings. A calibrated syringe with a clamp for holding a small rock specimen over its nozzle, the time of fall of a weighted piston being observed.

288—PRESSURE GAUGE

U. S. No. 2,459,155. A. L. Erickson and J. C. Kyle. Iss. 1/18/49. App. 9/19/45.

Pressure Cell. A reluctance-type pressure gauge having a central magnetic core and outer magnetic casing with a magnetic diaphragm across one and a coil on the core which may be connected in an impedance bridge.

U. S. No. 2,459,268. L. F. Elkins. Iss. 1/18/49. App. 4/24/44. Assign. Stanolind Oil and Gas Co.

Borehole Pressure Gauge. A surface-indicating borehole pressure gauge having inside it a liquid which is heated by a current supplied from the surface, the vapor pressure of the liquid acting against the well-fluid pressure through a diaphragm with an electric contact which connects a resistance thermometer into the circuit so that the vapor temperature may be observed.

U. S. No. 2,459,931. H. H. Furn. Iss. 1/25/49. App. 1/12/45. Assign. Thomas A. Edison, Inc.

Pressure Gauge. A differential pressure gauge having an aneroid capsule in a chamber with movement of the aneroid diaphragm transmitted by a lever to a pointer through a motion seal.

U. S. No. 2,460,076. J. F. Emerson. Iss. 1/25/49. App. 2/24/47. Assign. Kearfott Co., Inc.

Electromagnetic Pressure Gauge. A fluid pressure gauge having a cylindrical capsule whose shell is in the magnetic circuit of an impedance bridge, the capsule being made of an alloy whose permeability changes with stress.

U. S. No. 2,460,873. D. H. Clewell and D. C. Pfeiffer. Iss. 2/8/49. App. 1/1/45.

Vacuum Gauge. A thermal-conductivity vacuum gauge having several heated filaments with thermocouples mounted various distances away so that one may select a pair for the pressure range desired.

U. S. No. 2,461,635. A. M. Feller. Iss. 2/15/49. App. 10/6/44. Assign. Control Instrument Co., Inc.

Magnetostrictive Pressure Indicator. A pressure gauge in which the pressure is applied by bellows to compress two magnetostrictive rods, which in turn elongate two other similar rods, the rods being connected in a bridge circuit.

304—RADIOACTIVITY LOGGING

U. S. No. 2,458,596. G. Herzog. Iss. 1/11/49. App. 12/10/46. Assign. The Texas Co.

Radioactivity Well Logging Method. A gamma-ray logging method in which the ionization chamber pulses are passed into two integrating circuits respectively having short and long time constants and their outputs separately recorded.

U. S. No. 2,463,733. F. W. Albaugh. Iss. 3/8/49. App. 6/17/46. Assign. Union Oil Co. of Calif.

Well Logging. A method of well logging to distinguish oil-bearing horizons by running a gamma-ray log, then logging by bombarding with fast neutrons and observing secondary gamma-rays, and then bombarding with neutrons and one hour later measuring the gamma-rays from isotopes synthesized in the preceding run.

U. S. No. 2,464,930. G. Herzog. Iss. 3/22/49. App. 1/12/44. Assign. The Texas Co.

Method and Apparatus for Determining the Inclination of Substrata. A dipmeter having a source of penetrating radiation and three detectors of scattered radiation each shielded so that it picks up the radiation scattered from a 120° sector of the borehole wall.

308—RADIOACTIVITY MEASUREMENTS

U. S. No. 2,458,099. H. D. Roop. Iss. 1/4/49. App. 10/19/45.

Ionization Chamber. An ionization chamber having in contact with the gas a phosphor which gives off ultra-violet radiation when excited.

U. S. No. 2,458,632. J. H. Parsons. Iss. 1/11/49. App. 12/11/45. Assign. U.S.A.

Ionization Chamber. An ionization chamber with a cathode follower indicator circuit, the chamber having two parallel plates surrounded by a cylindrical shield connected to the cathode and an outer cylinder connected to ground.

U. S. No. 2,461,799–803. W. Armstrong. Iss. 2/15/49. App. 3/6/45, 9/20/45 and 5/26/47.

Apparatus and Method for Detecting and Measuring Radiant Energy for Locating Subterranean Petroleum Deposits. A radioactivity prospecting method using an ionization chamber shielded from local radiation and with a collimating tube of shielding material which admits only radiation from a narrow downward solid angle to enter the ionization chamber.

U. S. No. 2,462,088. H. Friedman. Iss. 2/22/49. App. 10/24/44.

Method of Measuring Thickness of Curved Sections and Apparatus Therefor. A method of measuring wall thickness of pipe by passing a beam of penetrating radiation tangentially into the pipe and picking up radiation scattered at right angles, the pipe being moved across the beam.

U. S. No. 2,462,140. H. C. Spicer. Iss. 2/22/49. App. 11/21/45.

Portable Battery-Powered Gamma-Ray Counting Rate Meter of High Sensitivity. A radioactivity detecting apparatus having a Geiger-Muller tube with amplifier, rectifier and indicator, and a relaxation oscillator which supplies pulses to an inductance for generating high voltage for the G-M tube.

U. S. No. 2,462,270. L. B. Lipson. Iss. 2/22/49. App. 9/7/43.

Method and Apparatus for Physico-chemical Analysis. A method of determining hydrogenous materials in soil by bombarding a sample with fast neutrons and measuring the quantity of slow neutrons produced with a Geiger-Muller counter.

U. S. No. 2,462,351. M. Blau and J. R. Carlin. Iss. 2/22/49. App. 10/22/46. Assign. Canadian Radium & Uranium Corp.

Area Measuring Device and Method. A method of measuring the area of a curve by masking out with a paper template part of the ionization current produced between two electrodes by a polonium layer on one of the electrodes.

U. S. No. 2,462,471. K. C. Crumrine. Iss. 2/22/49. App. 11/24/43. Assign. The Texas Co.

Radiation Detector. A neutron detector having a block of lead with a number of holes coated with boron carbide and a wire along the axis of each hole, the lead block forming the cathode and the wires the anode.

U. S. No. 2,465,821. R. Smoluchowski. Iss. 3/29/49. App. 5/31/46. Assign. General Electric Co.

Thin-Walled Geiger-Muller Counter. A Geiger-Muller counter having a thin window of polyvinylformal which is supported by a perforated plate or a wire mesh screen.

U. S. No. 2,465,886. O. G. Landsverk and E. O. Wollan. Iss. 3/29/49. App. 10/21/46. Assign. U.S.A.

Electrical Measuring Apparatus. A fiber electroscope having a bowed wire with a parallel fiber, the system being illuminated by a lamp and viewed through a microscope.

U. S. No. 2,465,938. F. R. Shonka. Iss. 3/29/49. App. 11/21/46. Assign. U.S.A.

Radiation Measuring Device. An ionization chamber and d-c amplifier circuit with a part of the output voltage fed back as voltage supply to the ionization chamber.

312—RADIO NAVIGATION

U. S. No. 2,461,005. G. C. Southworth. Iss. 2/8/49. App. 6/5/40. Assign. Bell Telephone Laboratories, Inc.

Ultra High Frequency Transmission. A microwave course-marking system using a number of microwave-reflecting range markers along the course and a multi-frequency transmitter and directional receiver on the ship, the reflectors being arranged as microwave horns having different frequency-reflection characteristics by which they may be identified.

U. S. No. 2,462,764. W. J. O'Brien. Iss. 2/22/49. App. 6/3/46. Assign. The Decca Record Co., Ltd.

Navigation System. A radio navigation system in which two pairs of spaced points radiate two pairs of different radio frequencies with the radiation cyclically arrested from one pair of points and radiating from the other pair of points the two pairs of radio-frequency signals with a fixed multiple phase relation between all frequencies.

U. S. No. 2,463,474. H. G. Busignies. Iss. 3/1/49. App. 3/5/45. Assign. Federal Telephone and Radio Corp.

Air Navigation System. A radio navigation system using a horizontally rotating directive transmitter which activates reflectors or reradiators at ground points to be marked which project the wave vertically.

U. S. No. 2,463,476. H. G. Busignies. Iss. 3/1/49. App. 9/26/45. Assign. Federal Telephone and Radio Corp.

Radio Navigation System. A radio beacon system in which the indication is produced by a light flashing through slits in opaque disks one of which is synchronized with the speed of the radio lighthouse and the other with the speed of a rotating receiving antenna.

316—RADIO RANGING

U. S. No. 2,459,165. J. Y. Houghton. Iss. 1/18/49. App. 11/11/44.

Method and Apparatus for Determining the Three-Dimensional Direction of Approach of an Electromagnetic Wave Front. An aberration-free radio direction-finding system in which the resultant magnetic vector is first found with a loop and then another line in the plane parallel to the wave front found by orienting a phase-discriminating pair of loops.

U. S. No. 2,460,798. T. O. McCarthy. Iss. 2/8/49. App. 5/13/44 and 3/12/46.

Radio Direction Finder. A system for introducing a deviation or parallax angle into the repeater unit of a direction finder by having the transmitter unit derive a correction-voltage generating unit whose output is added to that of the transmitter.

U. S. No. 2,460,806. H. G. Carter. Iss. 2/8/49. App. 8/10/45.

Direction Finder. A radio direction-finding loop for which a single null point is attained by having a uniform winding and additional turns bunched at one end of the coil.

U. S. No. 2,461,187. W. Steinmann. Iss. 2/8/49. App. 5/6/44 and 5/4/45. Assign. Patelhold Patenlverwertungs-& Elektro-Holding A.-G.

Direction Finding Apparatus. A radio locating system in which a number of directional beams are transmitted in different directions and modulated with an identifying signal while the array is rotated.

U. S. No. 2,461,213. W. D. Herschberger. Iss. 2/8/49. App. 6/16/39. Assign. Radio Corp. of America.

Distance Measuring Device. A radio pulse-echo system having in the transmitting circuit a network of condensers and spark gaps arranged so that the condensers are charged in parallel and discharged in series so as to apply an over-voltage to the oscillating circuit and produce a high-powered damped pulse.

U. S. No. 2,461,998. F. G. Patterson. Iss. 2/15/49. App. 11/17/43. Assign. General Electric Co.

Pulse Echo System and Pulse Indicating Means. A radio pulse-echo apparatus in which the transmitted and reflected pulses are shown on a c-r tube along with calibrating time-interval marks on an adjacent trace.

U. S. No. 2,462,188. R. H. Herrick. Iss. 2/22/49. App. 10/4/43. Assign. Automatic Electric Laboratories, Inc.

Radio Direction Finder. A radio direction finder using three equidistant loops in three parallel planes with the signals from the outer loops in opposition and periodically combined with the signals from the middle loop in alternate phases.

U. S. No. 2,462,898. A. G. Richardson and F. O. Chesus. Iss. 3/1/49. App. 2/6/43 and 8/29/45. Assign. Federal Telephone and Radio Corp.

Direction Finding System. A radio direction finder in which synchronism between the rotating antenna and the rotating field in the c-r tube indicator is maintained by two synchronous motors one of which is momentarily shut off if synchronism should be lacking.

U. S. No. 2,463,286. F. A. Kolster. Iss. 3/1/49. App. 4/1/44.

Radio Direction Finding System. A radio direction finder using two antennas with figure-eight patterns oriented at right angles to each other and indicating on crossed-pointer meters connected in rapid sequence to the combined antenna signals and to the individual antenna signals.

U. S. No. 2,463,475. H. G. Busignies. Iss. 3/1/49. App. 9/5/45. Assign. Federal Telephone and Radio Corp.

Direction Finder. A radio direction finder for steel ships in which two pairs of loops are used on opposite sides of the ship's hull with members of each pair separated by about one-quarter wave length and using the hull as a reflector.

U. S. No. 2,465,113. D. E. Norgaard. Iss. 3/22/49. App. 2/14/45. Assign. General Electric Co.

Pulse Echo System. A radio pulse-echo system in which reflections are indicated on a c-r tube as vertical bars against a uniformly illuminated background.

324—RECORDER

U. S. No. 2,460,411. S. Calvert. Iss. 2/1/49. App. 3/9/44. Assign. Raymond T. Moloney.

Sound Recorder. A phonograph recorder for recording sound on film with a stylus and having rollers underneath the film adjacent to but not directly under the stylus.

U. S. No. 2,461,322. C. M. Hathaway. Iss. 2/8/49. App. 9/13/45.

Recording Apparatus. A flight recorder for operation on a d-c supply having a vibrator inverter and a synchronous motor to drive the recording medium and a pressure-operated switch which turns the recorder off at low-speeds.

U. S. No. 2,461,892. H. G. Greig. Iss. 2/15/49. App. 8/16/46. Assign. Radio Corp. of America.

Electrolytic Recording. A chemical for impregnating facsimile recording paper containing an aliphatic diazotizable amine.

U. S. No. 2,462,145. F. R. Thomas. Iss. 2/22/49. App. 3/31/44 and 3/26/45. Assign. Creed and Co. Ltd.

Recording Electric Signals. An electrolytic recorder in which ordinary paper is used and the paper moistened with a chemical by a wick just before reaching the recording stylus.

344—SEISMOGRAPH AMPLIFIER

U. S. No. 2,463,553. R. C. Olesen. Iss. 3/8/49. App. 4/5/44. Assign. Consolidated Engineering Corp.

Integrating System. An electronic integrating amplifier using a network of condensers and resistors in the output circuit with a tap for an inverse feedback connection.

348—SEISMOGRAPH FILTER

U. S. No. 2,463,534. J. E. Hawkins. Iss. 3/8/49. App. 1/11/47. Assign. Seismograph Service Corp.

Method and Apparatus for Analyzing Seismographic Records. A seismograph analyzer for sound-on-film recordings in which the film is made into an endless belt and run over a transparent drum with an idler, and with a photocell inside the drum illuminated by a lamp and slit outside the drum.

352—SEISMOGRAPH INTERPRETATION

U. S. No. 2,463,788. G. M. McGuckin. Iss. 3/8/49. App. 12/10/46. Assign. Socony-Vacuum Oil Co., Inc.

Apparatus for Solution of Snell's Law. A mechanical device with an articulated system of graduated scales for computing problems based on Snell's law.

U. S. No. 2,463,789. G. M. McGuckin. Iss. 3/8/49. App. 12/10/46. Assign. Socony-Vacuum Oil Co., Inc.

Refracted Ray Calculating Device. A mechanical device with a graduated arm and a graduated circle for computing problems based on Snell's law.

356—SEISMOGRAPH MIXING

U. S. No. 2,461,173. J. O. Parr, Jr. Iss. 2/8/49. App. 8/27/45. Assign. Olive S. Petty.

Seismic Surveying. A seismograph apparatus in which avc for undesired frequencies is applied to the seismometer signals before mixing so as to attain better cancellation of undesired signals and amplification with avc applied after mixing.

360—SEISMOGRAPH PROSPECTING

U. S. No. 2,460,297. L. F. Kitto. Iss. 2/1/49. App. 1/31/45. Assign. one-half to Roderic Crandall.

Method of Geophysical Prospecting. A method of prospecting by firing a revolver or shot-gun shell into a hollow cylinder stuck into the ground and recording within one-half second the electrical signals of an adjacent carbon microphone.

U. S. No. 2,465,696. L. C. Paslay. Iss. 3/29/49. App. 10/11/47. Assign. Marine Instrument Co.

Method and Means for Surveying Geological Formations. A system of continuous seismic prospecting in water in which explosive charges are dropped from a boat which tows a cable streamer containing piezoelectric microphones and preamplifiers and recording on the boat.

372—SEISMOGRAPH VOLUME CONTROL

U. S. No. 2,461,173. J. O. Parr, Jr. Iss. 2/8/49. App. 8/27/45. Assign. Olive S. Petty.

Seismic Surveying. A seismograph apparatus in which avc for undesired frequencies is applied to the seismometer signals before mixing so as to attain better cancellation of undesired signals and amplification with avc applied after mixing.

U. S. No. 2,462,532. F. A. Morris. Iss. 2/22/49. App. 6/13/47. Assign. Stromberg-Carlson Co.

Sound System which Compensates for Variable Noise Levels. An automatic volume control for a public address system in which a microphone picks up the background noise, the rectified noise signal being subtracted from the rectified p-a signal and applied to control a variable-gain amplifier in the p-a system.

U. S. No. 2,462,551. D. S. Renner. Iss. 2/22/49. App. 11/5/42. Assign. Geophysical Service, Inc.

Amplitude Control. An avc system for seismograph amplifiers in which the resistors of an attenuation network are filaments whose temperatures are changed by a high frequency a-c which is controlled from the signal level.

U. S. No. 2,462,552. D. S. Renner. Iss. 2/22/49. App. 1/25/43. Assign. Geophysical Service Inc.

Initial Attenuator Control. An initial volume control for a seismograph amplifier which is automatically cut off when seismic signals appear so that thereafter avc alone may operate.

U. S. No. 2,463,430. P. J. Rudolph. Iss. 3/1/49. App. 1/9/45. Assign. Olive S. Petty.

Seismic Surveying. A seismograph volume control system which has high initial gain but with the gain reduced just before the first arrival by a relay connected to the firing circuit and thereafter self adjusting according to received energy.

376—SEISMOMETER

U. S. No. 2,458,581. F. A. Firestone and J. R. Frederick. Iss. 1/11/49. App. 5/21/46. Assign. Sperry Products, Inc.

Supersonic Inspection. A coupling between the crystal and the test material in a sonic inspection system using a piece of metal foil interposed between the crystal and the material with a thin liquid film between the foil and the crystal and also between the foil and the test material.

U. S. No. 2,460,153. R. Smoluchowski. Iss. 1/25/49. App. 7/30/46. Assign. General Electric Co.

Piezoelectric Crystal Holder. A device for holding the crystal against the surface of the test material in a sonic inspection system and having a spring which presses the crystal against the test surface and adjusting screws which tilt the crystal at the proper contact angle.

396—SOIL ANALYSIS

U. S. No. 2,462,270. L. B. Lipson. Iss. 2/22/49. App. 9/7/43.

Method and Apparatus for Physico-chemical Analysis. A method of determining hydrogenous materials in soil by bombarding a sample with fast neutrons and measuring the quantity of slow neutrons produced with a Geiger-Muller counter.

412—SPECIFIC GRAVITY MEASUREMENTS

U. S. No. 2,458,164. D. C. Hill and W. A. McGlashen. Iss. 1/4/49. App. 10/25/43.

Gravitometer. A device for determining the density of a gas by passing it into a whistle having a constant frequency resonator and indicator connected to it, the length of the whistle tube being observed for maximum response of the resonator.

420—SPECTROPHOTOMETER

U. S. No. 2,458,973. R. B. Barnes. Iss. 1/11/49. App. 9/25/43. Assign. American Cyanamid Co.

Infrared Spectrophotometry. An infrared spectrophotometer in which the beam is split by focusing it on two narrow slits whose beams are separated and one passed through the sample.

428—STRAIN GAUGE

U. S. No. 2,457,799. O. L. Altenberg. Iss. 1/4/49. App. 1/28/46.

Instrument for Detecting Strain in Translucent Materials. A device for detecting strains in glass by reflection of polarized light and having a tube with light source and polarizer and an observation tube with polarizer mounted on an arcuate bracket.

U. S. No. 2,458,354. A. V. de Forest. Iss. 1/4/49. App. 1/20/45. Assign. The Baldwin Locomotive Works.

Electric Strain Device with Temperature Compensator. A temperature compensated filament-type strain dynamometer in which the stressed element is composed of two materials with different temperature coefficients and whose relative lengths are adjustable.

U. S. No. 2,458,481. A. C. Ruge. Iss. 1/4/49. App. 9/1/44. Assign. The Baldwin Locomotive Works.

Load Weighing Device. A load dynamometer having two load-bearing end plates connected by a central square column with four filament-type strain gauges on its side surfaces and auxiliary columns which prevent bending but take only a part of the axial load.

U. S. No. 2,460,503. W. H. Howe. Iss. 2/1/49. App. 2/26/45. Assign. The Foxboro Co.

Apparatus for Measuring Liquid Level or Specific Gravity. A liquid level or specific gravity indicator having respectively a floating or submerged float whose apparent weight bends a supporting bar having a filament-type strain gauge whose resistance change is indicated.

U. S. No. 2,462,374. F. G. Firth. Iss. 2/22/49. App. 10/4/44. Assign. Philips Laboratories, Inc.

Stress Analysis by X-Ray Diffraction. An X-ray diffraction apparatus for determining internal stresses in materials.

436—SUBMARINE SIGNALING

U. S. No. 2,460,274. H. Benioff. Iss. 2/1/49. App. 12/9/42. Assign. Submarine Signal Co.

Submarine Signaling Apparatus. A submarine-signaling receiver or projector having a liquid-filled spherical shell whose forward hemispherical surface is made of sound-transparent material and having inside the shell a concave sound reflector which focuses the sound onto a transducer.

440—SURFACE TESTING

U. S. No. 2,460,726. J. P. Arndt, Jr. Iss. 2/1/49. App. 1/11/43. Assign. The Brush Development Co.

Surface Roughness Measuring Device. A surface-roughness tester having a sharp stylus and a rounded stylus each driving a piezoelectric crystal with the crystal outputs in opposition so that the effect of surface waviness is cancelled out and only roughness indicated.

444—SURVEYING APPARATUS

U. S. No. 2,464,911. S. E. White. Iss. 3/22/49. App. 4/2/48.

Pendulum Type Inclinometer. A vehicle inclination indicator having a pendulum whose inclination in a transverse plane is indicated by a directly connected pointer and inclination in the longitudinal plane is indicated by a pointer actuated through gears.

448—TENSION INDICATOR

U. S. No. 2,458,481. A. C. Ruge. Iss. 1/4/49. App. 9/1/44. Assign. The Baldwin Locomotive Works

Load Weighing Device. A load dynamometer having two load-bearing end plates connected by a central square column with four filament-type strain gauges on its side surfaces and auxiliary columns which prevent bending but take only a part of the axial load.

460—THERMOMETER

U. S. No. 2,460,773. A. G. Stimson. Iss. 2/1/49. App. 12/8/44. Assign. General Electric Co.

Temperature Sensitive Variable Inductance. An inductance having an inner core with a coil and an outer shell made of material whose permeability varies with temperature, the coil being part of a tuned circuit whose response is indicated.

464—THERMOSTAT CONTROL

U. S. No. 2,460,134. J. O. Lee. Iss. 1/25/49. App. 9/6/45.

Thermometric Alarm Switch. A mercury thermostat whose column has a series of platinum contact pins with heads on the outside which may be contacted by a sliding connector.

484—TRANSDUCER

U. S. No. 2,463,762. G. M. Giannini. Iss. 3/8/49. App. 11/14/41. Assign. Automatic Electric Laboratories, Inc.

Electroacoustical Transducer. A permanent-magnet moving-cone dynamic loudspeaker which has acoustic chambers on both sides of the cone with one set passing through the magnet structure.

U. S. No. 2,463,785. H. R. Lubcke. Iss. 3/8/49. App. 11/23/45. Assign. Thomas S. Lee Enterprises, Inc.

Electromechanical Device. A scanning galvanometer having two degrees of freedom having the mirror mounted in gimbals with the inner and outer gimbal rings wound with current coils.

U. S. No. 2,463,786. S. F. Lybarger. Iss. 3/8/49. App. 2/10/47. Assign. E. A. Myers & Sons.

Electromagnetic Mechanism for Bone Conduction Receivers, etc. A bone-conduction receiver having

a permanent magnet with coils on its pole pieces all suspended by leaf springs and an armature rigidly connected to the case.

U. S. No. 2,465,288. C. M. Sinnett. Iss. 3/22/49. App. 3/31/44. Assign. Radio Corp. of America.

Capacity Type Pickup. A condenser-type pickup having one stationary electrode and an electrode moved by the styles, the moving electrode being stiffened by a flange to prevent twisting.

U. S. No. 2,465,743. L. E. Norton. Iss. 3/29/49. App. 6/11/45 and 3/29/46. Assign. Radio Corp. of America.

Detector. An electronic device for detecting small displacements by a lever passing through a flexible diaphragm in the wall of a vacuum tube and moving a shutter which interrupts a constricted electron beam.

496—VISCOSIMETER

U. S. No. 2,459,483. J. C. Zimmer and A. Beerbower.Iss. 1/18/49. App. 12/6/44. Assign. Standard Oil Development Co.

Continuous Method for Determining the Apparent Viscosity of a Grease. A grease viscosimeter in which a constant volume pump feeds the grease through a tube and the pressure difference between two points indicated.

500—VOLTMETER

U. S. No. 2,463,527. F. W. Dunmore. Iss. 3/8/49. App. 9/21/45.

Measuring Potential Gradients in Space. A balloon carrying a radio transmitter with audio oscillator modulation, the modulating frequency being controlled by a bias voltage obtained from the potential gradient picked up by collector wires above and below the transmitter.

520—WELL SURVEYING

U. S. No. 2,459,499. J. H. Castel. Iss. 1/18/49. App. 12/17/43. Assign. Schlumberger Well Surveying Corp.

Casing Joint Locator. Apparatus for locating the annular recess at casing collars and having a finger urged outward by a spring and arranged to open an electrical contact when it drops into a recess and indicating at the surface.

Reprints of this Index for use as a Supplement to the Geophysics Patent Abstract Index portion of the *Cumulative Index, 1931–1947, of the Publications of the Society of Exploration Geophysicists* are available at the Business Office of the Society at 50 cents each.

INDEX OF PATENTS ABSTRACTED IN GEOPHYSICS, 1947–1948

O. F. RITZMANN*

INTRODUCTION

The following index supplements the Patent Abstracts section of the Cumulative Index of 1948. It covers the nine issues of *Geophysics* beginning with April, 1947 through April, 1949, thereby completing the indexing of abstracted geophysical and related patents issued by the U. S. Patent Office through 1948. The form of the index parallels that used in the Cumulative Index. However, in conformity with the present practice of printing an abstract under more than one subject classification if such appears appropriate, all pages numbers are given in the patent number section of the index. In the case of a patent having more than one inventor, it is indexed under each inventor's name in the inventor's section of the index.

It may be of interest that *Geophysics* published abstracts of 416 patents issued during 1947, and 474 during 1948. Patents of interest are found by going through the weekly Official Gazette of the U. S. Patent Office and examining copies of patents of interest. The list of abstracted patents represents a major portion of those patents which are pertinent to the art and which are believed to be of interest to exploration geophysicists. The very brief abstracts are presented primarily to indicate the nature of the subject matter so that the reader may judge whether further investigation is warranted. The abstracts, though all written by the present author, vary considerably in form of composition depending on the complexity of the subject matter. The aim has been to make them as informative as possible, but required brevity forces many to be largely indicative and correspondingly less informative. The abstracts are not to be construed in any sense as an interpretation of the patents.

The author of the abstracts and of the index appreciates permission of the officials of the Gulf Oil Corporation to undertake this abstracting and to use its secretarial staff in this connection, and acknowledges the assistance of Mrs. M. L. C. Ritzmann in checking the manuscripts and proofs.

* Gulf Oil Corporation Patent Department.

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2,418,543	M. Camras	XII, 4, 669
2,419,195	S. J. Begun	XII, 4, 669
2,419,476	S. J. Begun	XII, 4, 669
2,420,671	J. B. Little	XII, 4, 669
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2,457,699	R. A. Marsen	XIV, 2, 181
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2,412,742	G. Muffly	XII, 2, 270
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2,416,824	T. De Forest	XII, 3, 450
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2,419,591	C. J. Quigley	XII, 4, 670
2,421,583	A. A. Stuart, Jr.	XII, 4, 670
2,421,775	F. B. Doane	XII, 4, 670
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2,427,062	F. Massa	XIII, 1, 108
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2,436,084	B. L. Weller	XIII, 3, 469
2,437,476	H. M. Parker	XIII, 3, 469
2,437,935	E. M. Brunner and E. S. Mardock	XIII, 3, 469
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2,440,999	H. L. Anderson	XIII, 4, 631
2,442,314	A. F. Reid	XIII, 4, 631
2,442,617	S. Rosenblum	XIII, 4, 631
2,443,365	E. H. Wakefield	XIII, 4, 631
2,443,591	E. Banks and T. Bland	XIII, 4, 632
2,443,857	G. Herzog	XIII, 4, 632
2,449,697	A. Graves and T. J. Dawes	XIV, 1, 78
2,452,524	H. Metten	XIV, 2, 182
2,456,233	A. Wolf	XIV, 2, 183

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2,413,620	G. Guanella	XII, 2, 272
2,414,469	E. J. Isbister	XII, 3, 452
2,414,537	L. L. Lakatos	XII, 3, 452
2,419,970	R. B. Roe and J. B. Gray	XII, 4, 671
2,420,016	R. C. Sanders, Jr.	XII, 4, 671
2,420,017	R. C. Sanders, Jr.	XII, 4, 672
2,422,100	H. S. Huff	XII, 4, 672
2,423,305	H. Fletcher	XIII, 1, 109
2,424,560	C. W. Earp	XIII, 1, 109
2,425,008	G. T. Royden	XIII, 1, 110
2,428,427	A. V. Loughren	XIII, 2, 275
2,436,376	R. Bown	XIII, 3, 470
2,436,479	D. G. C. Luck	XIII, 3, 470
2,438,987	C. E. G. Bailey	XIII, 4, 632
2,439,663	H. M. Lewis	XIII, 4, 632
2,439,846	O. H. Dicke	XIII, 4, 632
2,440,755	W. J. O'Brien	XIII, 4, 632
2,442,692	P. F. G. Holst and L. R. Kirkwood	XIII, 4, 632
2,444,171	R. C. Sanders, Jr.	XIII, 4, 632
2,444,445	E. J. Isbister	XIV, 1, 78
2,444,578	J. Neufeld	XIV, 1, 78
2,445,361	G. Mountjoy, G. D. Hulst, Jr. and E. Schoenfeld	XIV, 1, 78
2,449,977	H. G. Busignies	XIV, 1, 78

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2,410,666	G. W. Leck	XII, 2, 272
2,410,868	L. De Forest	XII, 2, 273
2,412,111	W. S. Wilson	XII, 2, 265
2,413,620	G. Guanella	XII, 2, 272
2,413,637	B. D. Loughlin	XII, 2, 273
2,413,981	D. G. C. Luck	XII, 3, 452
2,413,982	D. G. C. Luck	XII, 3, 452
2,414,798	H. T. Budenbom	XII, 3, 453
2,415,088	E. N. Dingley, Jr.	XII, 3, 453
2,415,094	W. W. Hansen and R. H. Varian	XII, 3, 453
2,415,095	R. H. Varian and W. W. Hansen	XII, 3, 453

2,415,591	F. C. P. Henroteau	XII, 3, 453
2,415,855	A. M. Skellett	XII, 3, 453
2,415,954	D. G. C. Luck	XII, 3, 453
2,415,955	D. G. C. Luck	XII, 3, 454
2,415,981	I. Wolff	XII, 3, 454
2,416,351	J. C. Schelleng	XII, 3, 454
2,418,156	J. H. Bollman	XII, 4, 672
2,418,308	D. G. C. Luck	XII, 4, 672
2,419,590	A. Preisman	XII, 4, 672
2,419,987	W. L. Carlson	XII, 4, 672
2,419,994	C. W. Hansell	XII, 4, 673
2,420,395	G. B. Greene	XII, 4, 673
2,421,009	H. G. Busignies and A. G. Richardson	XII, 4, 673
2,421,028	A. P. King	XII, 4, 673
2,421,394	J. C. Schelleng	XII, 4, 673
2,422,134	R. C. Sanders, Jr.	XII, 4, 673
2,422,135	R. C. Sanders, Jr.	XII, 4, 673
2,422,157	I. Wolff	XII, 4, 673
2,422,295	T. T. Eaton	XII, 4, 674
2,422,382	H. T. Winchel	XII, 4, 674
2,422,654	E. Bruce	XII, 4, 674
2,422,655	G. Hecht	XII, 4, 674
2,422,696	L. A. Meacham	XII, 4, 674
2,422,697	L. A. Meacham	XII, 4, 674
2,423,064	C. W. Earp, I. R. J. James and R. F. Cleaver	XII, 4, 674
2,423,437	H. T. Budenbom	XIII, 1, 110
2,424,263	J. R. Woodyard	XIII, 1, 110
2,424,984	R. B. Hoffman	XIII, 1, 110
2,425,383	D. G. C. Luck	XIII, 1, 110
2,425,385	L. E. Norton	XIII, 1, 110
2,425,386	L. E. Norton	XIII, 1, 110
2,425,387	L. E. Norton	XIII, 1, 111
2,428,058	R. O. Wise	XIII, 1, 111
2,429,623	W. F. Hoisington	XIII, 2, 275
2,430,283	D. W. Epstein	XIII, 2, 275
2,431,344	A. H. Reeves	XIII, 2, 275
2,434,263	H. Diamond, F. W. Dunmore and W. S. Hinman, Jr.	XIII, 3, 470
2,434,917	M. Fuchs	XIII, 3, 470
2,434,977	R. H. Worrall	XIII, 3, 470
2,435,569	W. L. Barrow	XIII, 3, 470
2,435,615	R. H. Varian, W. W. Hansen and J. R. Woodyard	XIII, 3, 470
2,436,672	R. C. Sanders, Jr.	XIII, 3, 470
2,437,695	K. G. Jansky	XIII, 3, 470
2,438,946	A. G. Richardson, F. O. Chesus and F. G. Thomas	XIII, 4, 632
2,440,250	E. M. Deloraine, E. Labin and P. F. M. Gloess	XIII, 4, 633
2,440,268	R. Hardy	XIII, 4, 633
2,440,682	P. G. Hansel	XIII, 4, 633
2,440,777	J. Lyman	XIII, 4, 633
2,441,658	E. D. Blodgett and D. S. Bond	XIII, 4, 633
2,443,718	E. D. Blodgett	XIII, 4, 633
2,444,031	H. G. Busignies	XIII, 4, 633
2,444,388	D. De Vries	XIII, 4, 633
2,445,014	I. Wolff	XIV, 1, 78
2,445,779	R. Hardy	XIV, 1, 78
2,446,244	M. R. Richmond	XIV, 1, 79
2,446,520	D. Blitz	XIV, 1, 79
2,446,630	N. W. Bryant, E. E. Crump, M. R. Dungan, and J. Strand	XIV, 1, 79
2,446,850	C. S. Root	XIV, 1, 79
2,447,502	R. J. Hardy	XIV, 1, 79
2,447,728	F. E. Bartholy	XIV, 1, 79
2,448,041	R. Marchand	XIV, 1, 79
2,448,059	A. D. Smith, Jr. and H. M. Guthman	XIV, 1, 79
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2,449,553	P. G. Hansel	XIV, 1, 80

2,449,859 H. F. Penfold and J. P. Della Corte ..... XIV, 1, 80
2,449,978 T. H. Clark ..... XIV, 1, 80
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2,452,564 M. K. Goldstein ..... XIV, 2, 183
2,452,675 J. H. Newitt ..... XIV, 2, 183
2,456,666 C. S. Agate and A. H. Cooper ..... XIV, 2, 183

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2,415,880 N. A. Hassler ..... XII, 3, 454
2,415,981 I. Wolff ..... XII, 3, 454
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2,422,143 R. M. Somers and R. C. Van Camp ..... XII, 4, 675
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2,427,342 A. H. Andrews, Jr. ..... XIII, 1, 111
2,428,369 E. W. Kammer ..... XIII, 2, 275
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2,436,384 H. Fletcher, J. F. Müller and K. D. Swartzel, Jr. ..... XIII, 3, 471
2,440,841 K. De Boer ..... XIII, 4, 633
2,445,272 J. H. Keegan ..... XIV, 1, 80
2,445,832 E. W. Kellogg ..... XIV, 1, 80
2,446,324 U. L. Di Ghilini ..... XIV, 1, 80
2,446,479 S. J. Begun ..... XIV, 1, 80
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2,449,291 P. S. Gay ..... XIV, 1, 81
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352 SEISMOGRAPH INTERPRETATION
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356 SEISMOGRAPH MIXING
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2,431,600 A. Wolf ..... XIII, 2, 276

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2,423,970 L. W. Gardner ..... XIII, 1, 111
2,427,421 F. Rieber ..... XIII, 1, 111
2,438,526 C. H. Waterman ..... XIII, 3, 471
2,449,921 A. Wolf ..... XIV, 1, 81
2,450,352 R. G. Piety ..... XIV, 1, 81
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364 SEISMOGRAPH RECORDER
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2,440,971 E. M. Palmer ..... XIII, 4, 634

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2,428,369 E. W. Kammer ..... XIII, 2, 276
2,433,160 G. W. Rusler ..... XIII, 2, 276
2,435,903 O. F. Ritzmann ..... XIII, 3, 471
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"Integraltafel—erster Teil—Unbestimmte Integrale" by Wolfgang Grobner and Nikolaus Hofreiter. Published by Springer, July 1948. iv+166 pages. $5.40.

This book lists well over one thousand indefinite integrals arranged systematically according to the integrand. It represents an extension of the familiar B. O. Pierce and H. B. Dwight "Table of Integrals." It is somewhat more extensive than either of these collections. It is planographed from a very legible manuscript. The text is in German but it is not a serious handicap even to one who is unable to read German.

W. M. Rust, Jr.

Teoria e Pratica dei Variometri Magnetici da Campagna by Carlo Morelli. Publication no. 223, Istituto Geofisico, Trieste, 1946. Pp. 165.

This book is written in the Italian language and deals with the theory and operation of magnetometers. It consists of two sections and a twenty-four page bibliography. Several basic types of instruments, mainly of the suspended magnet variety, are described in the first section. A brief description of the air-borne type is also appended. The second section, which is nearly two-thirds of the text, is a detailed description of the theory and operation of the Schmidt magnetic balance. A knowledge of the fundamentals of magnetism is assumed. Some chapter references are given in addition to the bibliography. The publications cited are generally familiar, but a few rare ones are included. The bibliography is quite comprehensive and is divided into sections on terrestrial magnetism, general magnetic measurements, Schmidt balance, general prospecting, magnetic prospecting, magnetic surveys, interpretations, magnetic properties of rocks, diurnal variations, and artificial anomalies.

Since the subject is well covered in English and other languages, interest in this book should be primarily from Italian students and geophysicists, except for the interest of others in the extensive bibliography.

Alex Frosch

The Swedish Geophysical Society, founded in 1920 to promote geophysical research and Scandinavian as well as international collaboration in geophysics, has recently initiated publication of a quarterly journal, *Tellus*. This publication is made possible through a grant from the Swedish government. Each issue will contain 48 to 64 pages, the page size being 179×250 mm. While articles may be in English, French, or German, it is interesting to note that the initial issue was entirely in English. In line with the pre-eminence of Scandinavian geophysicsts in meteorological and oceanographic fields of investigation, the initial issue contains four meteorological papers by T. Bergeron, E. Palmen, A. Nyberg and C. G. Rossby, an article on the geochronology of the deep ocean bed by H. Pettersson, and a paper on recent ionospheric measurement in Lapland by O. Rybeck.

The subscription price is $6.00 per year. Communications relating to manuscripts and subscriptions may be addressed to the Editor of *Tellus*, Fridhemsgatan 9, Stockholm, Sweden.

Charles C. Bates

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American Journal of Science, Vol. 247, No. 2 (February, 1949), No. 3 (March, 1949), No. 4 (April, 1949)

Annales de Geophysique, Tome 4, Annee 1948, Fascicule 3 (December 1948)

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Canadian Geophysical Bulletin, Vol. II, No. 3 (1 July–30 September, 1948)

Economic Geology, Vol. XLIV, No. 2 (March–April)

Erdol und Kohle, Heft No. 2, (February, 1949), Heft, No. 3, (Marz, 1949)

Gassmann, F. (Separates)

Uber Kleine Bewegurgen In Nicht Vallkommen Elastischen Korpern

Zur Interpretation Des Schwercdefizites In Den Schweizer Alpen

Geofisica Pura e Applicata, Vol. XIV, Fasc. 1–2, (January–March, 1949)

Institute of Petroleum Review, Vol. 3, No. 25 (Jan., 1949), Vol. 3, No. 26 (Feb., 1949), Vol. 3, No. 27 (March, 1949)

Instituto de Fisiografia y Geologia:

El Puelchense de Buenos Aires y Su Fauna, Rosario XXXV, 1948

Journal of Applied Physics, Vol. 20, No. 3 (March, 1949), Vol. 20, No. 4 (April 1949)

Journal of Geophysical Research, Vol. 54, No. 1 (March, 1949)

Journal of the Institute of Petroleum, Vol. 34, No. 300 (Dec., 1948), Vol. 35, No. 301 (Jan., 1949), Vol. 35, No. 302 (February, 1949)

Journal of Petroleum Technology, Vol. 1, No. 3 (March, 1949), Vol. 1, No. 4 (April, 1949)

Nafta, No. 3, Roczink V, (March, 1949)

The Quarterly Journal of the Geological Society of London, Vol. CIV, Part 2 (January 31, 1949)

The Review of Scientific Instruments, Vol. 20, No. 2, (Feb., 1949), Vol. 20 No. 3, (March, 1949), Vol. 20, No. 4, (April, 1949)

World Petroleum, (March, 1949) and (April, 1949)

CONTRIBUTORS

LEO J. PETERS was trained at the University of Wisconsin during the period 1915 to 1929. He received the B.S. degree in 1919 and the Ph.D. degree in 1929. During the years 1919 to 1929 he spent short periods with the Chicago Telephone Company, the American Telephone & Telegraph Company, and 15 months in the Geophysical Research Laboratory of the Marland Oil Company. He taught at the University of Wisconsin while carrying on graduate work and was an Assistant Professor of Electrical Engineering when he left. He joined Gulf Research & Development Company in July of 1929 and is at present Chief of the Geophysical Operations Division. He is a member of the American Physical Society, the Institute of Radio Engineers, the American Institute of Electrical Engineers, the Society of Exploration Geophysicists, and the Pittsburgh Geological Society.

LEO J. PETERS

W. D. CORTRIGHT

W. D. CORTRIGHT was educated at the University of California where he received his B.S. degree in petroleum engineering in 1924. He has been employed by the Tide Water Associated Oil Company in California since 1927. His experience has been in various branches of petroleum exploration and development work including applied geophysics. He is now the San Joaquin Valley district geologist for the above company with headquarters at Bakersfield, California. Mr. Cortright is a member of the American Association of Petroleum Geologists, and was recently elected secretary of the Pacific Coast Section of the Society of Exploration Geophysicists.

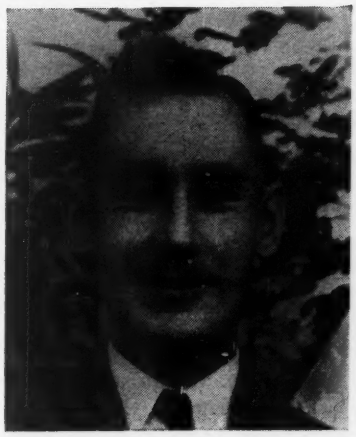
KENNETH S. COHICK

KENNETH S. COHICK received his B.S. degree in Physics and Mathematics from Juniata College, Pennsylvania, in 1933, and his M.A. in Physics from Oberlin College in 1934. He was employed as a High School teacher two years in Pennsylvania after which he joined Shell Oil Company, Incorporated in 1936 as a member of their Geophysical Department. He has been with Shell until the present time working entirely on the Pacific Coast.

He is a past member (now inactive) of the American Association of College Physics Teachers, a member of the Society of Exploration Geophysicists, and the Pacific Coast Section of S.E.G.

ROBERT J. WELLS was graduated from the University of California at Los Angeles in 1934 with a B.A. degree in science. During 1935 he was an engineer for the American Potash and Chemical Company, and joined National Geophysical Company in 1936. For the next four years he held various positions on National's seismic crews in the midcontinent area. From 1940 to 1942 he was engaged as a well logging engineer for Baroid Sales Division of National Lead Company in California. Since 1942 he has been a geophysicist with the Richfield Oil Corporation in Bakersfield, California. He is a member of the American Association of Petroleum Geologists and the Society of Exploration Geophysicists.

ROBERT J. WELLS



G. E. HIGGINS

G. E. HIGGINS obtained his B.Sc. from the Royal School of Mines, London, England, in 1938, and is an Associate of that organization. From 1938 until 1940 he was engaged in carrying out geological and torsion balance gravity surveys for the Caracas Petroleum Company in Venezuela.

Early in 1941 he was transferred to Trinidad Leaseholds Limited and from then on he successively devoted his time to surface mapping and subsurface investigation. Later, he acted as liaison between geophysical contractors working for T.L.L. and the Geological Department of Trinidad Leaseholds Limited and concentrated on geologic interpretation of seismic and gravity surveys. He was instrumental in locating the first deep well in the Siparia basin located on seismic evidence.

LUDGER MINTROP

LUDGER MINTROP was born on a farm near Essen, Germany in 1880. After 2 years work in coal- and ore-mines he studied geology, mining engineering and mining surveying at the Mining-Academy of Berlin and at the University of Technology in Aachen where he became acquainted with geophysics under the leadership of Karl Haussmann, a well known scientist in the field of earth-magnetism. From Aachen Mintrop went to the University of Goettingen as a student of geophysics at the Institute of Emil Wiechert, the famous seismologist. Here he acquired his D.Ph. degree and began his experiments with artificial earthquakes in 1908. Mintrop held positions as head of the geophysical and mining surveying department at the school of mines in Bochum in the Ruhr district, as Professor of mining surveying and applied geophycis at the University of Technology and at the University in Breslau (Silesia) as well as of applied geophysics at the University of Technology in Aachen. At all three places Mintrop erected and managed seismological observatories. In 1921 Mintrop founded the Seismos Company in Hannover, Germany, in order to put to practice geophysical methods of exploration, especially seismic refraction shooting. After field work in Germany, Austria, Poland, Holland and Sweden he came to the United States and took the first records of refraction shooting on July 24, 1923 near Ponca City (Okla.). In June 1924 his company discovered the Orchard saltdome in Fort Bend County, Texas. As president of the Seismos Company and afterwards Mintrop did much traveling in European countries, including Egypt, as well as in Canada, Mexico and especially within the United States which he has visited 19 times. In 1934 he retired from business and at the end of 1948 from his academic position. Mintrop lives now on his farm where he was born and raised, spending most of his time with scientific work and consulting mining companies for the introduction of geophysical methods of exploration. Mintrop is a member of the German Academy of Natural Science (founded in 1652) and an Honorary Member of the Society of Exploration Geophysicists.

SOCIETY ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following candidates for membership in the Society. This publication does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it to the president within thirty days. (Names of references appear in parentheses after the name of each nominee.)

ACTIVE

Wayne Rosser Abbott (J. A. Sharpe, R. C. Coffin, M. J. Gould)
Robert Harrison Barnes (T. O. Hall, Chester Sappington, Jack Martin)
Olin Grogan Bell (D. H. Gardner, H. G. Patrick, R. S. Duty, Jr.)
John Berning (Oscar Weiss, E. B. Papenfus*, B. V. Lombaard*)
Edward Alpha Boudreaux (G. B. Lamb, W. J. Osterhoudt, J. E. McGee)
Jerome Lamar Burns (L. I. Freeman, E. R. Locke, L. V. S. Roos)
Urbain Joseph Chaput (H. W. Brown, R. L. Craig, P. M. Tucker)
Allen Anthony Chernosky (D. P. Carlton, W. M. Rust, Jr., D. H. Gardner)
William Edward Dickson (K. E. Burg, C. H. Green, J. E. Jonsson)
John David Gallacher (J. L. Kezeler, R. P. Green, F. L. Bishop)
Gordon George Gibson (H. J. Kidder, A. J. Oden, C. J. Chapman)
John David Gill (P. E. Nash, J. C. Menefee, J. A. Lester)
T. A. Halbrook (C. H. Green, H. B. Peacock, K. E. Burg)
Richard Benton Hale (F. Goldstone, W. Hafner, L. K. Mower)
Thurman Leo Jones (O. C. Clifford, Jr., A. E. McKay, C. H. Hightower)
Joseph Alfred Keeling (G. H. Speirs, J. E. Dorris, C. C. Cody)
Laurence Keeney King (L. F. Athy, J. M. Crawford, E. V. McCollum)
Alf Klaveness (B. H. Treybig, Jr., C. C. Zimmerman, H. W. McDonnold)
Frederic Stanley Kramer (R. A. Peterson, M. C. Born, B. F. Howell, Jr.)
William C. Krumbein (M. K. Hubbert, William Lamb, L. J. Peters)
Thomas Maroney (M. A. Boccalery, Henry Salvatori, J. M. Desmond)
Alfred Norman McDowell (W. E. Franks, W. C. Merritt, S. R. Marsh)
Oliver Barto McReynolds, Jr. (H. G. Patrick, P. J. Rudolph, A. Kohler)
Leland George Megason (A. E. McKay, O. C. Clifford, Jr., J. V. Franklin)
James Willard Miller (C. E. Buffum, Daniel Silverman, J. D. Eisler)
Arthur Alvern Milton (H. M. Thralls, C. E. McClure, A. J. Barthelmes)
Harold Brett Morris (K. C. Thompson, W. A. Matthews, Karl Dyk)
Herman Neibauer (L. L. Nettleton, F. H. Thomsen,* Bylaws, Art. III, Sec. 2)
Harold Frederick Patterson (H. E. Itten, C. J. Long, J. R. Foster*)
Carol Winthrop Payne (J. L. Morris, G. E. Wagoner, Newton Page)
Stanley Gordon Pearson (L. I. Brockway, L. W. Gardner, G. J. Blundun)
Tiziano Rocco (Henry Salvatori, M. A. Boccalery, Dean Walling)
Roy Otho Smith (R. H. Ray, J. C. Pollard, A. J. Oden)
Roy Walter Tronrud (H. W. Rose, W. G. Smiley, Jr., R. E. Rettger)
Willem Johannes van Riel (A. van Weelden, B. Baars, V. P. Ulrich)

ASSOCIATE

Leland Cummins Adams (J. W. Fishback, W. A. Matthews, K. C. Thompson)
George Earl Adkins (W. Hoogenhout,* M. A. Mawby,* E. R. Cottrell*)
Buford Morris Baker (W. G. Green, R. P. Green, L. M. Swift*)
Thomas David Barber (K. C. Thompson, R. A. Weingartner, W. A. Matthews)

* Reference who is not a member of the Society.

David Bartlett (W. M. Rust, Jr., R. A. Geyer, L. G. Howell)
Harold Julius Blumberg (Oscar Weiss, M. Mawby,* Bylaws, Art. III, Sec. 2)
Marshall Duncan Bradford (Dean Walling, V. E. Prestine, O. A. Strange)
Richard Eugene Byers (C. H. Green, P. E. Haggerty, R. W. Olson)
Walter Thomas Caldwell (C. W. Blakey, R. B. Ross, R. C. Herron)
William Charles Calledare, Jr. (Dean Walling, Jack Desmond, V. E. Prestine)
John Lorraine Care (L. B. Trombla, R. H. Glover, J. A. Ballard)
Michael Cresap Carpenter (W. W. Newton, W. B. Heroy, Jr., T. R. Shugart)
Robert Franklin Catchings (J. F. Harang, W. B. Duty, R. A. Steinmayer*)
Hendrick Paulus Coster (E. J. P. van der Linden, E. B. Lindsey, R. S. Finn)
Warren Leslie Davis (C. K. Shepherd, H. R. Prescott, Frank Searcy)
Richard Charles John Edwards (Oscar Weiss, Bylaws, Art. III, Sec. 2)
Peter Garwood (Oscar Weiss, Bylaws, Art. III, Sec. 2)
Joseph Goodman (Oscar Weiss, Bylaws, Art. III, Sec. 2)
Edward Albert Gribi, Jr. (A. I. Levorsen, J. J. Rupnik, N. J. Christie)
Frans Hardin Hammons (J. W. Fishback, W. A. Matthews, C. J. Long)
Jesse Lee Hendricks (C. H. Green, Earl Thomas, F. J. Agnich)
Daniel Edward Herlihy (Evan Watts, W. B. Roper, H. E. Granberry)
Edith May Hess (L. K. Mower, A. E. Smith, O. B. Manes)
Frank Stanley Honeycutt (Dean Walling, Robert Dyk, John Sloat)
John Albert Hooton (C. H. Green, V. W. Teufel, C. H. Elston)
Norman Gardner Johnson (A. L. Ladner, W. T. Born, R. L. Lay)
Gerald Sidney Kaplan (Oscar Weiss, Bylaws, Art. III, Sec. 2)
George Vernon Keller (S. J. Pirson, L. O. Bacon, D. J. Stuart)
Edward Charles Kovelan (H. H. Moody, E. F. McMullin, M. C. Kelsey)
John Frank Krisher (H. H. Moody, E. F. McMullin, M. C. Kelsey)
Harry Stanley Lieberman (R. H. Dana, Paul Ledyard, R. E. Davis)
Earl Wagner Lipscomb (G. E. Bowler, R. W. Olson, Frank J. Feagin)
Edward Ramsey Loyd, Jr. (C. H. Green, E. F. McMullin, V. W. Teufel)
Marshall Edward Macdonnell (R. F. Bennett, Donald Crary, S. B. Stewart)
William Joseph Major (W. H. Gibson, R. L. Wales, H. H. Beach)
Lawrence Francis Malarin (S. C. Stoneham, Maurice Sklar, O. F. Van Beveren)
Harry McBurnett, Jr. (M. S. Hathaway, W. W. Hawthorne, C. H. Hightower)
Kenneth Barry Medlock (R. T. Chapman,* C. H. Hickox,* Louis Lenz*)
John Ohman (W. M. Rust, Jr., D. H. Clewell, M. M. Slotnick)
Donald Robert Oksa (M. S. Hathaway, C. H. Hightower, O. C. Clifford, Jr.)
Thomas Ortiz (R. F. Aldredge, B. F. Rummerfield, T. A. Manhart)
Edgar Ralph Penn (V. W. Teufel, G. D. Cloepfil, W. E. Ware)
Jocelyn Pereira (Oscar Weiss, Bylaws, Art. III, Sec. 2)
Ferol Dean Sears (Andrew Gilmour, Frank Borman, Robert Davenport)
Charles Alfred Shannon (R. N. Bills, Andrew Gilmour, A. W. Taylor)
George Lutfi Sorour (Oscar Weiss, Bylaws, Art. III, Sec. 2)
Robert John Spittel, Jr. (W. H. Myers, M. W. Harding, F. H. Agee)
Robert Pierce Thomas (Perry Byerly, H. R. Thornburgh, F. H. Agee)
James Ernest Thompson (H. W. Rose, W. G. Smiley, Jr., R. E. Rettger)
Thomas Frederick Wallis, Jr. (E. J. Stulken, K. E. Burg, V. W. Teufel)
Charles Gunning Walters (F. H. Kennedy, T. R. Shugart, W. W. Newton)
Robert Bruce Wilcoxon (J. K. Pawley, G. J. Long, Miller Quarles)
Howard Ava Willis (W. C. Wagner, H. E. Itten, C. J. Long)
James Earl Wilson (Dean Walling, V. E. Prestine, Dupree McGrady)
Raymond Clyde Zongker (Jack Cooper, J. D. Eisler, Daniel Silverman)
George Henry Zwiebel, Jr. (Lorenz Shock, W. J. Harkey, K. H. Waters)

REINSTATEMENTS

Vernon Alvin Peterson (Active)

Albert Edward Johnson (Active)

RESIGNATION

L. H. Wylie (Student)

STUDENT MEMBERS ELECTED

The following students have been elected to student membership in the Society in accordance with Article III, Section 5, of the Bylaws.

William C. Abbott, *St. Louis University*
Rudolph D. Black, *Washington University (St. Louis)*
Max C. Brewer, *Washington University*
William Henry Burke, Jr., *Rice Institute*
Victor F. Capatch, *Pennsylvania State College*
Thomas J. Countis, *University of Colorado*
Donald W. Jones, *Pennsylvania State College*
Curtis Harry Keenan, *Pennsylvania State College*
Harold Lloyd Krivoy, *University of Utah*
Leonard Volk Lombardi, *Stanford University*
Nelson E. Lurton, Jr., *Washington University*
James Robert Moore, III, *University of Houston*
Robert L. Nelson, *California Institute of Technology*
Carel Otte, *California Institute of Technology*
William A. Patterson, *Washington University*
John Renowden Reese, *California Institute of Technology*
Robert O. Wilkat, *Washington University*

ADDITIONAL APPLICATIONS APPROVED FOR PUBLICATION

ACTIVE

Willis Omer Clark (J. C. Pollard, R. G. Elms, J. R. Jubran)
William Lee Fellows (H. R. Moorman, P. P. Conrad, A. J. Z. Caan)
Charles Spurlin Johnson (L. A. Scholl, Jr., R. L. Lay, A. A. Hunzicker)
Jacques Le Blanc (E. G. Leonardon, J. C. Legrand, E. F. Stratton)
Dosh T. McCreary (R. L. Lay, V. E. Child, M. L. Benke)
John Robert Monkhouse (R. H. Ray, R. S. Duty, J. B. Nichols)
Don Lane Sprinkle (Richard Williams, V. H. Waddell, W. C. Clark)
Lewis Beverly Stumpf (C. H. Gregory, Ted Rozsa, O. G. Holekamp)

ASSOCIATE

Carl Dalquest Bearden (J. M. Nash, G. D. Lambert, R. C. Kendall)
Alden Lowery Capps (E. J. Handley, D. R. Weichert, R. L. Williams)
Louis Castelli (E. J. Handley, W. J. Tellington, W. H. MacGuire)
Owen Echohawk (E. J. Handley, R. L. Williams, D. R. Weichert)
Arthur Douglas Foster (V. W. Teufel, H. B. Peacock, C. H. Elston)
Robert William Guipre (J. O. Ayres, F. J. Agnich, P. V. Hodge)
Riddell L. Hawk (C. C. Zimmerman, Paul C. Cook, J. C. Karcher)
Donald Page Melton (R. L. Palmer, J. B. Nichols, Eugene Frowe)
Romaine Reivere (F. Goldstone, C. H. Gregory, O. G. Holekamp)
John Warren Rhymes (Frank Ittner, C. E. Reel, T. E. Dennis)
John Warren Sadler (H. B. Peacock, V. W. Teufel, Chris Elston)
Thomas Dale Trostle (F. J. Agnich, C. H. Green, Earl Thomas)
Richard Hal Wesley (H. L. Scharon, Joel Swartz)

REINSTATEMENTS TO ACTIVE

Jack Maxwell Desmond

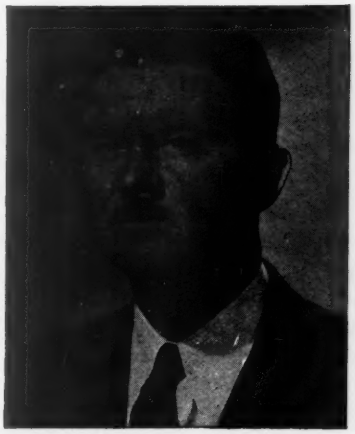
LeRoy Leonard Hammial

TRANSFER FROM ASSOCIATE TO ACTIVE

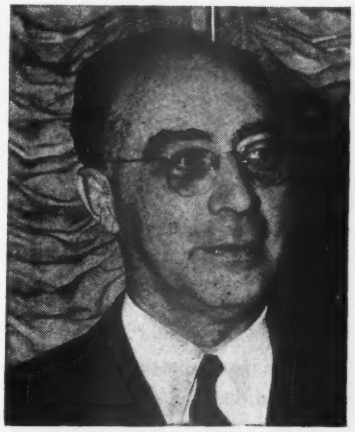
Perry Michael McNally

OFFICERS FOR THE YEAR ENDING APRIL, 1950

L. L. NETTLETON, *Past President*



GEORGE E. WAGONER, *Vice-Presiden*



ANDREW GILMOUR, *P resident*

KENNETH E. BURG,
Secretary-Treasurer

RICHARD A. GEYER, *Editor*

PAPERS PRESENTED OR READ BY TITLE AT THE TECHNICAL SESSIONS OF THE NINETEENTH ANNUAL MEETING HOTEL JEFFERSON, ST. LOUIS, MISSOURI MONDAY MORNING, MARCH 14, 1949

Place: Gold Room
9:00 A.M. to 12:00 NOON

M. M. SLOTNICK AND GEORGE E. WAGONER, *Presiding*

1. *Elevation Surveying by Precision Barometric Means.*

A. A. STRIPLING, R. A. BRODING, and E. S. WILHELM, Magnolia Petroleum Company, Field Research Laboratories, Dallas, Texas.

An instrument for rapid and economic elevation surveying is presented. The instrument is based on precision barometric measurements and is sensitive to changes in atmospheric pressure equivalent to elevation differences of 0.1 foot. Elevations are measured with a probable error of 0.3 foot, and data are shown for a survey around a 10-mile closed loop containing thirteen stations in which the closure is 1.7 feet. Some of the theoretical aspects relating barometric pressure to elevation are reviewed, and the practical limitations imposed by the erratic nature of the atmosphere are discussed. A field technique is described, and a comparison with transit surveying is made.

2. *Velocity Treatment Applicable to Southeastern New Mexico.*

C. G. DAHM, Magnolia Petroleum Company, Dallas, Texas.

Because of a strong regional gradation in both near-surface and over-all average velocity in New Mexico and West Texas, special measures are needed to yield seismic maps which correctly delineate the attitude of the subsurface layers. Regional maps depicting the variation of near-surface velocity through a generous use of uphole surveys are suggested. Regional maps showing the variation of over-all velocity to a given horizon and their use in computing depths are found to have distinct advantage. Examples of maps both of near-surface and of over-all average velocity in New Mexico are shown. Comparison is made of results obtained by use of a simple time depth curve and by use of the suggested method.

3. *Discussion of Steep-Dip Seismic Computing Methods.*

R. B. RICE, Phillips Petroleum Company, Bartlesville, Oklahoma.

This paper presents a comparison of the results obtained by the application of several standard computing techniques to the computation of steep-dip seismic data. Formulas for the horizontal displacements and depths of reflection points are derived for the various methods, assuming velocity to be a parabolic function of depth; and the results obtained for two typical velocity functions over a wide range of reflection and stepout times are compared graphically. In addition, the over-all effort of applying these results to the computation of several types of structural profiles is studied.

4. *Fault Interpretation in Southwest Texas.*

MILLER QUARLES, JR., United Geophysical Company, Inc., Pasadena, California.

Many of the oil-bearing structures around the Gulf Coast and in Southwest Texas are found along a distinctive type of low-angle normal faulting.

Reflection seismograph shooting across the faults gives normal information on the downthrown side but produces two types of distorted and misleading data below the fault plane on the upthrown side. One type of distortion gives a time lag up to 0.100 second to reflections plotted vertically below the upper limit of the fault plane. If this time lag is not recognized, the fault may be located as far as a mile from its true position. The second type of distortion below the fault plane is an apparent increase in dip toward the fault plane in the deeper beds. The magnitude is great enough to cause some reflecting horizons on the upthrown side of the fault to be plotted actually deeper than those on the

downthrown side. This could readily cause error in locating the fault and determining the magnitude and direction of throw.

The first "time-lag" type of distortion is explained by a refraction pattern downward along a portion of the fault plane before the energy is reflected back from the recognized interface. The second "increased-dip" type of distortion may be the result of a reflection time lag through the gouge zone of the fault. The field across sections show both types of fault distortion and the interpretation used.

5. *Seismic Problem Encountered Across Faults.*

E. J. STULKEN, Geophysical Service Inc., Dallas, Texas.

If effect of overburden upon velocity is over-estimated, erroneous depths are computed beneath fault surfaces. Examples evince this and the need for correctly appraising velocity changes. Analyses of velocity determinations afford one basis for adjusting data near faults.

6. *Correlation of Gravity Anomalies with Seismic and Geological Data in California.*

P. F. CLEMENT, Western Gulf Oil Company, Bakersfield, California.
G. R. WATSON, Gulf Research and Development Company, Pittsburgh, Pennsylvania.

A considerable amount of gravity work in the San Joaquin Valley, California, indicates that known structures usually result in well defined gravity anomalies. In some cases large geological structures do not result in clear gravity anomalies, and conversely some gravity anomalies can not be explained by seismograph data. Some examples are given of gravity anomalies that are and others that are not correlated with known structural data. It is concluded that the explanation of residual gravity anomalies that occur where structural evidence is not indicated by the seismograph probably lies in undetermined irregularities within the basement or in local lateral variations in density within the sedimentary section.

MONDAY AFTERNOON, MARCH 14, 1949

BUSINESS MEETING AND TECHNICAL SESSION

Place: Gold Room

2:00 P.M. to 5:00 P.M.

Part I. Business Meeting
L. L. NETTLETON, *Presiding*
Part II. Technical Session
M. KING HUBBERT, *Presiding*

1. *Gravity Meter as a Geodetic Instrument.*

GEORGE P. WOOLLARD, 3921 Winnemac Avenue, Madison, Wisconsin.

The development of a special high range (5400 mgal.) gravity meter this year by the Houston Technical Laboratory which was temperature compensated and weighed only 5 pounds made it possible for the first time to check the Potsdam system of gravity on a world-wide basis within a reasonable period of time and at comparatively little expense. Working under the auspices of the Office of Naval Research of the United States Navy and using military air transportation, the writer covered approximately 82,000 miles in a 3-month period, re-occupied many of the national primary gravity bases in the northern hemisphere, and set new reference bases in many localities where there had been no previous observations. Closures on loops involving several thousand miles and periods of 1 to 2 weeks showed after correction for drift based on overnight observations an average error of 0.4 mgal. Repeat observations showed a similar degree of accuracy. Reading accuracy of the instrument was of the order of 0.1 mgal. The accumulative error was small, as was indicated by closure on the world circuit loop (0.02 mgal.). With the exception of pendulum gravity base values in the Hawaiian and Philippine Islands, most national gravity base values were found to be accurate on a relative basis to 1 or 2 mgals. Countries to which the foregoing degree of accuracy applies are United

States, Canada, England, France, Holland, Denmark, Sweden, Finland, and Japan. Although permission could not be obtained to re-occupy the Potsdam base in the Russian zone of Germany, through indirect ties it appears the Potsdam system is about 12 mgals. in error.

2. *Regional Correction of Gravity Data.*

RAOUL VAJK, Standard Oil Company (N. J.) New York, New York.

The author gives a definition of the regional gravity effect and presents a critical discussion of various methods for its determination. The advantages of the method based on the analysis of the gravity curves (developed by the author 20 years ago) is emphasized in contrast to the mechanical averaging methods.

3. *New System of Seismic Exploration.*

THOMAS C. POULTER, Stanford Research Institute, Stanford, California.

Studies on the absorption of energies from underground explosions revealed that up to 95 per cent of the blast energy was absorbed within a few feet of the charge, when the initial amplitude was large. With low initial amplitude, as low as 5 per cent of the energy was absorbed over the same path. Experiments indicated that wave motion with low initial amplitude was transmitted comparatively well by the weathered layer. In general, when charges are detonated above the surface of the ground in such a way as to generate a flat wave front that strikes the ground over a large area, sufficient energy is transmitted for reflection seismic prospecting. Methods of producing a flat wave front and the advantages and disadvantages of the Poulter method are presented.

SOCIETY OF EXPLORATION GEOPHYSICISTS
AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

TUESDAY MORNING, MARCH 15, 1949

JOINT MEETING

Place: Gold Room

9:00 A.M. to 11:30 A.M.

PRESIDENTIAL ADDRESS

Geophysics, Geology, and Oil Exploration.

L. L. NETTLETON, President of S. E. G., Gravity Meter Exploration Company, Houston, Texas.

As geophysics has matured in recent years, its important place as a tool in oil exploration has been generally recognized. The operation of the partnership between geologist and geophysicist is relatively straightforward in reflection seismograph exploration as the geophysical maps are similar to those with which geologists are familiar. In geophysical methods based on potential fields (gravity and magnetic) the relations to geology are not so direct and the possible ambiguities are much greater. Close cooperation of geophysicist and geologist in the evaluation of such surveys should produce particularly fruitful results. Some specific examples of both regional and local nature will be illustrated and discussed.

JOINT MEETING

TUESDAY AFTERNOON, MARCH 15, 1949

Place: Gold Room

2:00 P.M. to 5:00 P.M.

Report on Geophysical Activity for 1948.

E. A. ECKHARDT, Gulf Research and Development Company, Pittsburgh, Pennsylvania.

In the preparation of the report for this year, the writer is happy to report the assistance of

Herbert Hoover, Jr., D. C. Skeels, and A. A. Brant, who have become members of the committee. As a result, the report is world-wide as compared with the United States coverage only, of last year's report, and includes mining as well as petroleum geophysics.

Precision Detail Gravity Survey of Jameson Area, Coke County, Texas.

HART BROWN, Brown Geophysical Company, Geophysical Associates, Houston, Texas.

The Jameson field, on the eastern shelf of the Permian basin, was discovered in December, 1946. It produces from a Lower Pennsylvanian reef limestone. Since few, if any, conventional gravity surveys of the Jameson area produced a significant gravity anomaly, an experimental high-density gravity survey was conducted immediately following the field discovery. A station density of 15 per square mile was achieved. Great pains were taken to obtain higher than customary precision of each field measurement. Careful terrain corrections were applied. Maps of raw and residual gravity are presented. The subsequent drilling of 36 field wells now provides an accurate reef map. This reef map is compared with the gravity anomaly to bring out the degree of correlation which may be expected from similar reefs.

Geophysical Exploration for Limestone Reefs.

F. J. AGNICH, Geophysical Service Inc., Dallas, Texas.

A discussion of various geophysical methods in relation to their possible value in locating limestone reefs. Special emphasis is laid on the gravity meter and the seismograph. Variations in velocities of seismic waves in reef limestones are considered and the effects on reflections from below a reef body are examined. The relationships between shallow and deep seismic data are investigated and it is concluded that time isopach maps of such data are extremely valuable. Several methods of detailing limestone reefs are presented. Some suggestions for a program of exploration for reefs are given and the need for "reef mindedness" in interpreters is emphasized.

WEDNESDAY MORNING, MARCH 16, 1949

Place: Ivory Room

9:00 A.M. to 12:00 NOON

ROY L. LAY, E. V. MCCOLLUM AND K. E. BURG, *Presiding*

1. *Detection of Salt Domes with the Airborne Magnetometer.*

H. WAYNE HOYLMAN, Fairchild Aerial Surveys, Inc., Los Angeles, California.

This paper points out theoretically the geological conditions that must exist for the detection of salt domes by magnetic surveys. Results are illustrated by airborne magnetometer profiles across known Gulf Coast salt domes. The success and limitations of these results are discussed.

2. *Crystal Shaketable for Geophone Studies.*

THOMAS BARDEEN, Gulf Research and Development Company, Pittsburgh, Pennsylvania.

A comparison is made between shaketables driven by piezo-electric crystals and those of conventional design. The general construction of crystal shaketables and the auxiliary equipment necessary for geophone studies are discussed. The theory of geophone motion shows that a measurement of phase shift between the geophone output and the crystal shaketable driving voltage can be used to determine the natural frequency and damping of the moving mass of the geophone. The crystal shaketable gives a simple method for routine testing of geophones both in the laboratory and the field.

3. *On Stratification of Earth's Crust Resulting from Seismic Studies of a Large Explosion and of Great Earthquakes.*

LUDGER MINTROP, 22a Essen-Werden, Barkhovenalle 36, Germany.

On April 18, 1947, an explosion of 10 million pounds of deep buried munition took place on the rocky island of Helgoland in the North Sea near Hamburg. The elastic waves in the ground have been

registered by 20 seismographs which were set up in a profile up to a distance of 608 km. (380 miles). The time curves of reflections and refractions show a number of formations, partly unknown heretofore. The results have been confirmed by a new study of the seismograms of great earthquakes, i.e. of Messina (Italy) on December 28, 1908. Though the energy released by this natural earthquake was about ten thousand times larger than that of the Helgoland explosion, the amplitudes of the first impeti in the registrations of the earthquake observatories were so small that they had not been recognized at that time. But the high sensitiveness of the modern seismographs, especially of the field instruments, made it possible to discern the forerunners even in the seismograms of the artificial earthquake of Helgoland.

The following have been determined by the author.

Wave Velocities km/s			
Longitudinal	*Transverse*	*Depth km.*	*Remarks*
3.5 (Average)	ca 2 (Average)	0.4	Sediments (solid)
5.2	2.9	4– 13	Granitic (solid)
6.5	3.6	13– 28	Basaltic (solid)
8.1	4.5	28– 57	Peridotite (solid)
9.2	5.0	57–110	? (solid)
ca 7	?	110–118	? (plastic)
11.0	6.2	118–170	? (solid)
16.3	8.8	170–180	? (solid)
ca 9	?	180–	(Alternating plastic and solid)

The most remarkable result is the determination of a plastic formation at the depth of 110–118 km. These results are discussed and compared with those obtained by Gutenberg and Richter, Hayford, Helmert, and Angenheister.

4. *Direct Approach to Magnetic Interpretation and its Practical Applications.*

Leo J. Peters, Gulf Research and Development Company, Pittsburgh, Pennsylvania.

This paper discusses the solution of the inverse potential problem and its practical application in the interpretation of field data which have a scalar potential distribution. The discussion will be in terms of the interpretation of magnetic data. Among the topics discussed are: the direct calculation of basement relief, the derivation of the potential and the horizontal components of the field from the vertical intensity, the continuation of the field upward, the continuation of the field downward toward its source, the calculation of derivatives of the vertical intensity with special attention to the second and fourth, and the estimation of depths to igneous basement rocks. The uses of these tools and the information of practical value which can be obtained by their use are discussed and illustrated. Methods of rapidly making calculations using magnetic field data are given.

5. *Composite Reflections.*

Norman Ricker and R. D. Lynn, The Carter Oil Company, Tulsa, Oklahoma.

This paper discusses the development of a method of reflection seismic prospecting based on the use of the seismic PS phase—a disturbance which has traveled from the shot to the reflecting bed as a dilatational wave, and from the reflecting bed to the horizontal component geophones as a shear wave. The use of the method in delineating the Homer and Cotton Valley structures near Minden, Louisiana, is described in detail. The method appears to be applicable to regions where an unconsolidated subsurface extends downward from the earth's surface to a single hard bed serving as the reflector. Criteria for identifying the disturbance as a composite reflection are given and the advantages and limitations of the method are discussed.

6. *Recent Developments in Geophysical Exploration Equipment.*

C. H. CARLISLE, Humble Oil and Refining Company, Houston, Texas.

A discussion of a series of slides showing several types of specialized geophysical exploration equipment and techniques used in present-day field operations, as well as some of the types of equipment and techniques formerly used in the exploration program.

WEDNESDAY AFTERNOON, MARCH 16, 1949

Place: Ivory Room

2:00 P.M. to 5:00 P.M.

SIGMUND HAMMER AND CURTIS H. JOHNSON, *Presiding*

1. *Review of Explosion Data.*

R. A. PETERSON, United Geophysical Company, Pasadena, California.

Results of wartime studies of explosion phenomena have been released in numerous reports and summaries. On the basis of these data a model explosion of geophysical interest is described, and the influence of the surrounding water, soil, or air medium, on the explosion pulse is discussed.

2. *Computation of Second Vertical Derivatives of Geomagnetic Fields.*

ROLAND G. HENDERSON AND ISIDORE ZIETZ, United States Geological Survey, Washington, D. C. Published by permission of the director of the United States Geological Survey.

Second vertical derivitives of magnetic fields, because of their high resolving power, are often very useful in interpreting magnetic anomalies. Formulas are developed which permit their ready numerical computation. Comparisons are made between resulting approximate values and the rigorous values obtained for simple idealized fields. The similarity between maps of second vertical derivatives of fields and those of certain types of residual fields is discussed.

3. *Seismic Wave Propagation.*

D. H. CLEWELL AND R. F. SIMON, Magnolia Petroleum Company, Field Research Laboratories, Dallas, Texas.

Speculations are made regarding the significance of the well known observation that seismic reflection energy is usually in the frequency range from 20 to 100 cycles per second. The general absence of reflected energy below 20 cps is attributed to the fact that the wave lengths of seismic waves in this frequency range are becoming large compared with the thickness of reflecting beds; accordingly, the reflection coefficients are small, the downward traveling low-frequency energy is unweakened by reflections, is transmitted efficiently, and can only return to the surface by refraction.

To continue with the hypothesis, it can be assumed that as the frequency is increased the wave lengths become comparable with the horizontal discontinuities represented by stratification and more efficient reflection takes place with the result that reflected energy is returned and detected at the surface. At still higher frequencies the wave lengths become comparable with small inhomogeneities distributed at random throughout the geologic section, and are therefore diffused and scattered to such an extent that transmission into the earth is seriously limited. This high frequency scattered energy diffuses back to the surface and appears on the seismogram as "hash," unless eliminated by filters.

Such a speculative picture of seismic energy propagation accounts qualitatively for (1) the continuous reception of random energy that is always superimposed upon the reflection energy, (2) the tendency for deep reflections to be of lower frequency than shallow reflections, and (3) the fact that theoretical considerations of absorption do not account for known attenuation of high frequency seismic energy.

4. *Propagation of Elastic Waves in a Liquid Layer Overlying a Semi-infinite Elastic Solid.*

FRANK PRESS AND MAURICE EWING, Columbia University, Department of Geology, New York, New York.

The Pekeris theory of normal mode propagation of explosion sound in two liquid layers is ex-

tended to include the case of a solid bottom. Curves giving phase velocity, group velocity, amplitude, vertical pressure distribution as a function of frequency are presented. The relative merits of geophones and hydrophones for underwater seismology and the best depth for each type of instrument are discussed in the light of the theory. The characteristics of an incoming signal are described.

5. *Blast Damage Claim Racket.*

H. M. ENGLE, Consulting Engineer, Los Angeles, California.

A serious situation has developed in the construction industry and other operations involving blasting. Such operations, no matter how well controlled, are usually followed by a flood of blast damage claims. Most of such claims have no basis of fact, and the filing of them has become a racket. Blasting operators, and their insurance carriers and agents, are largely responsible for the development of this situation. In the past they have taken the course of least resistance and paid them off as nuisance claims. If steps are not taken to stop this racket, blasting operations of all kinds will be seriously hampered. Steps should be taken by all interested parties to fight these claims to the last recourse of law, except in those rather infrequent cases where legitimate claims are filed.

6. *Progressive Detonation of Multiple Charges in a Single Seismic Shot.*

LORENZ SHOCK, National Geophysical Company, Inc., Dallas, Texas.

The relative efficiencies of various sizes of explosive charges for the generation of seismic energy were investigated and a procedure devised whereby a number of charges of the most efficient size would be detonated progressively in such a manner that the energy from all the individual charges would arrive simultaneously at the recording position. The results of investigations of this system of progressive detonations using both horizontal and vertical spacings of the individual charges are presented and its possible application in reflection and refraction seismic surveys is discussed.

7. *Close Control and Detail with the Magnetometer.*

By title.

V. L. JONES, consulting geophysicist, Tulsa, Oklahoma.

8. *Upward Continuation of Anomalies in Total Magnetic Intensity Fields.*

By Title, by permission of the Director, U. S. Geological Survey.

ROLAND G. HENDERSON and ISIDORE ZIETZ, United States Geological Survey, Washington, D. C.

MEETINGS OF THE LOCAL SECTIONS

DALLAS GEOPHYSICAL SOCIETY

April 7, 1949

The April Meeting of the Dallas Geophysical Society was held in the Dallas Power and Light Company Auditorium, April 7, 1949.

President Newton presided with about 100 members in attendance. Mr. Newton mentioned that the Society was proud of Mr. K. E. Burg who was elected secretary and treasurer of the S. E. G. at the recent election.

Announcement was made that the Dallas Geological Society has invited the Dallas Geophysical Society to join them in a dinner dance, Friday, May 27th at the Dallas Country Club. The dinner dance will be a joint affair between the two Societies. Mr. C. H. Green is chairman of the Entertainment Committee.

Mr. Newton stated that the results of the balloting for the new slate of officers would be given at the May meeting. All who had not sent in ballots were requested to do so immediately. The program for the May meeting was announced to be a paper by Mr. Kintz, of the U. S. Bureau of Mines, on "Hazards of Static Electricity in Seismic Prospecting."

Announcement was then made of the Regional Meeting of the Society of Exploration Geophysicists sponsored by the Houston Section of the S. E. G. on Friday, April 15, 1949 in the Rice Hotel in Houston.

Mr. Newton introduced the speaker of the meeting, Dr. L. L. Nettleton who spoke on "Regional Gravity and Regional Geology." Considerable discussion was stimulated by Dr. Nettleton's interesting paper.

The Meeting was then adjourned and a coffee and doughnut session followed.

May 16, 1949

Hazards of Static Electricity in Seismic Prospecting, G. M. Kintz, U. S. Bureau of Mines

The May meeting of the Dallas Geophysical Society was held at Fondren Auditorium, at eight o'clock Monday, May 16, 1949. President Newton presided with a total of 71 members in attendance.

Mr. Newton announced the results of the election of officers for the term 1949–1950 as follows:

President, O. C. Clifford, Jr., Atlantic Refining Co.
1st Vice President, D. Ray Dobyns, Magnolia Petroleum Co.
2nd Vice President, H. C. McCarver, Seaboard Oil Co.
Secretary-Treasurer, T. R. Shugart, Geotechnical Corp.

District Representatives for the coming year are Paul E. Nash, Magnolia Petroleum Company and W. W. Newton, Geotechnical Corporation.

An announcement was made of the joint dinner dance of the Dallas Geological Society and the Dallas Geophysical Society to be held May 27, 1949 at the Dallas Country Club and members were urged to send in reservations as soon as possible. The suggestion was made that a picnic be held in the Fall to which the members of the Dallas Geological Society be invited.

The secretary announced that the active members of the Society totaled 194. A brief statement was given as to the finances of the Society and it was announced that an audit would be conducted by the Financial Committee consisting of C. W. Chamberlain, Chairman and Dick Thompson.

President Newton introduced the speaker of the evening, G. M. Kintz of the U. S. Bureau of Mines. Mr. Kintz assisted by Mr. H. F. Brown gave a series of realistic examples of the hazards of static electricity with particular emphasis on those encountered in seismic prospecting. Mr. Hal Anderson of the Geophysical Service, Inc. then analyzed the possibilities of premature explosions caused by radio frequency waves. After a discussion period the meeting was adjourned.

W. G. Smiley, Jr.
Secretary Treasurer

PACIFIC COAST SECTION

May 6, 1949 (Annual Spring Meeting)

This event was held at the El Tejon Hotel in Bakersfield, California during the afternoon and evening of May 6, 1949. The meetings were conducted by Mr. R. C. Dunlap, Jr., President, and Mr. J. C. Waterman, Northern District Vice President and Chairman of the program committee.

Attendance at the afternoon or technical session was approximately 85. The evening meeting was a joint meeting with the San Joaquin Geological Society, and was attended by approximately 150 persons.

Afternoon Meeting (2–5 P.M.)

Seismic Wave Propagation, D. H. Clewell and R. F. Simon, Magnolia Petroleum Company, Dallas, Texas. (Read by Curtis H. Johnson, General Petroleum Corp., Los Angeles)

Shoran Surveying, John Coffman, Overseas Navigation, Inc., New Orleans, La.

Report on S. E. G. Business Meeting, St. Louis Convention, Dean Walling, Western Geophysical Co., Los Angeles.

Gulf Coast Offshore Seismic Work, Color Film with comments by Joe B. Hudson, Humble Oil & Refining Co., Los Angeles

Geophysical Exploration for Limestone Reefs, F. J. Agnich, Geophysical Service Inc., Dallas, Texas (Read by E. A. Kiesler, Geophysical Service, Inc., Bakersfield, Calif.)

A Review of Certain Papers Presented at the National Meeting at St. Louis, March 14–17, 1949, Curtis H. Johnson, General Petroleum Corp., Los Angeles.

Evening Session (7–10:30 P.M.)

Exploring the Gran Chaco of Paraguay, E. B. Noble, Union Oil Company of Calif.

Mr. R. C. Dunlap, Jr., President of the Pacific Coast Section conducted this meeting. The main paper of the evening was given by Mr. E. B. Noble, Manager of Exploration, Union Oil Company of California. The subject was "Exploring the Gran Chaco of Paraguay." This extensive paper covered varied phases of the exploratory program including particularly the geophysical work. The talk was profusely illustrated by both lantern slides and colored movies. From the voluminous applause and later comments it was apparent that Mr. Noble's efforts were thoroughly enjoyed and highly appreciated by all present.

Numerous visitors of note were present including particularly Dr. R. I. Levorsen who spoke briefly and introduced a group of students and instructors from Stanford University.

Mr. J. C. Waterman extended thanks to the members who contributed papers at the afternoon program and to the other members of the program committee present, including Messrs. Maynard Harding, Ted Ellsworth, and Gene Vallat.

W. D. CORTRIGHT
Secretary Treasurer

ARK-LA-TEX GEOPHYSICAL SOCIETY

Feb. 16, 1949

A luncheon meeting of the Ark-La-Tex Geophysical Society was held at noon, Wednesday, Feb. 16, 1949, in the Main Dining Room of the Caddo Hotel in Shreveport, La. Mr. Harry M. Buchner, President of the Society, presided. A record attendance included 102 members and guests.

The featured speaker, Dr. L. L. Nettleton, President of the Society of Exploration Geophysicists, was introduced by Mr. Carl L. Bryan. Dr. Nettleton spoke interestingly and in detail on the relation of prominent regional gravity anomalies in the south and southwestern United States with associated regional geological features. A spirited general discussion followed delivery of the paper.

March 11, 1949

The luncheon was held in the Colonial Room of the Caddo Hotel at noon, Friday, March 11, 1949 with Mr. Harry M. Buchner, President of the Society, presiding. Thirty-three members and guests were present.

Announcement was made reminding members of the Society that Mr. R. M. Wilson and Mr. J. Ryan Walker had been elected for two-year terms in the spring of 1948 to represent the Society at the national conventions of the Society of Exploration Geophysicists. Under such circumstances, Messrs. Wilson and Walker would again represent the Society at the 1949 convention in St. Louis as they had in 1948 at Denver.

Mr. N. G. Johnson of the Explosives Department of E. I. Du Pont de Nemours, Wilmington, Delaware, was introduced by Mr. L. R. Fischer. Mr. Johnson gave an interesting talk on the history and present stage of development of seismograph explosives and made informal comments on experimental work being done on explosives designed for use in the Poulter Method.

April 27, 1949

A luncheon meeting was held in the Main Dining Room of the Caddo Hotel at noon, Wednesday, April 27, 1949, with Mr. Harry M. Buchner, President, presiding. Thirty-eight members and guests were present.

Mr. R. M. Wilson reported on the meeting of the Business Committee of the Society of Exploration Geophysicists in convention at St. Louis, Mo. The principal item reported was the approval of affiliation of the Ark-La-Tex Geophysical Society with the Society of Exploration Geophysicists, subject to minor changes in the Ark-La-Tex Geophysical Society constitution as outlined in a letter from Dr. W. M. Rust, Jr., to Dr. L. L. Nettleton, dated March 2, 1949. Mr. Wilson moved that the

Society accept the submittal of the proposed constitutional amendments. After seconding by Mr. B. B. Burroughs, the motion was unanimously approved by the members present.

Mr. Buchner introduced the speaker, Mr. E. E. Gustafson of the Bell Aircraft Corporation. Mr. Gustafson talked interestingly and informatively on the development and use of the helicopter in geophysical exploration and showed a short motion picture of the helicopter in use in the marshes of southern Louisiana.

CARL L. BRYAN
Secretary-Treasurer

GEOPHYSICAL SOCIETY OF TULSA

March 10, 1949

The regular monthly meeting of the Geophysical Society of Tulsa was held on Thursday evening, March 10, 1949 in Lorton Hall on the University of Tulsa campus. Dr. A. B. Bryan presided. One hundred twenty-five members and guests were present.

The nominating committee consisting of A. B. Bryan, R. Clare Coffin and D. J. Handley announced the nominees for offices of the Society for 1949 to 1950.

For President
W. T. Born
L. O. Seaman
For 1st Vice-President
E. M. McNatt
H. M. Thralls
For 2nd Vice-President
G. N. Smith
N. J. Christie
For Secretary-Treasurer
J. J. Rupnik
N. R. Sparks

Mr. V. L. Jones announced that a social function was being planned for the Society and requested that he be given any suggestions or ideas.

Dr. Norman Ricker, Senior Research Physicist, of The Carter Oil Company, presented a paper on "Composite Reflections." Dr. Ricker discussed a new seismic method using "Composite" Reflections (i.e., reflections which travel downward as longitudinal waves and return upward as transverse waves). Composite reflections are recorded with horizontal component geophones and are simple and easy to correlate.

The use of the method in mapping the Homer and Cotton Valley structures in Louisiana was detailed and slides were shown. Criteria for identifying composite reflections and the advantages and limitations of the method were discussed. The meeting adjourned at 8:45 o'clock.

April 13, 1949

The regular monthly meeting of the Geophysical Society of Tulsa was held on Wednesday evening, April 13, 1949, in Lorton Hall on the University of Tulsa campus. Eighty-five members and guests were present. In the absence of the President, the First Vice-President, Mr. F. F. Campbell, presided.

A report on the annual meeting of the council of the Society of Exploration Geophysicists was given by the District Representative for our Society, Dr. James E. Hawkins. A possible increase in S. E. G. dues to $8.00 or $10.00 to meet the added expenses of the national Society was the principal business reported.

Plans for an annual picnic by the Geophysical Society of Tulsa at the Sand Springs Park was announced to the membership by the Second Vice-President, Mr. V. L. Jones and by the Secretary-Treasurer, Mr. G. D. Lambert. The following picnic committees were announced:

Food and Drink Committee.....Co-chairmen: V. L. Jones & E. J. Handley
Dance Committee.....Chairman: G. N. Smith
Registration Committee.....Chairman: Harold M. Land
Arrangements Committee.....Chairman: G. D. Lambert
Public Relations Committee.....Chairman: Paul Lyons

Dr. L. L. Nettleton was introduced by the newly elected president of the S. E. G. and member of the Tulsa Section, Mr. Andrew Gilmour. Dr. Nettleton discussed the inadequacy of explanation for large regional gravity features and the need for close geological and geophysical cooperation in their study and interpretation. Maps of the southeastern part of the United States were presented, showing regional gravity (10 mgl. contours) and the corresponding part of the tectonic map. Implications and difficulty of explanation of large gravity anomalies were discussed.

The meeting was adjourned at 9:00 P.M.

May 12, 1949 (Annual Meeting)

Progressive Detonation of Multiple Charges in a Single Seismic Shot, Lorenz Shock, National Geophysical Company, Inc., Dallas, Texas.

Mr. Shock discussed the relative efficiencies of various sizes of explosive charges for generation of seismic energy and a method of progressive detonation so that energy from individual charges will arrive simultaneously at the recording position. Results were presented for both horizontal and vertical spacings of individual charges, and possible application in reflection and refraction shooting were discussed.

The following officers were elected for the year 1949–1950:

President, W. T. Born, Geophysical Research Corp.
First Vice President, E. M. McNatt, The Carter Oil Co.
Second Vice President, N. J. Christie, United Geophysical Co.
Secretary-Treasurer, N. R. Sparks, Stanolind Oil & Gas Co.

G. D. LAMBERT
Secretary-Treasurer

THE COLORADO SCHOOL OF MINES SOCIETY OF STUDENT GEOPHYSICISTS

Feb. 16, 1949

The February 16th meeting of the Society of Student Geophysicists was held at the Sigma Alpha Epsilon fraternity house. It was announced that the voting for the proposed amendments to the constitution was completed. The amendments carried and are now accepted as part of the constitution and by-laws of the Society. The meeting was turned over to Mr. Carl W. Blakey, of The Seismograph Service Corp., who showed colored movies of exploration in Iraq. Mr. Blakey was made Honorary Life Member of our Society.

Thirty-four seniors of the geophysics class attended the convention in St. Louis the week of March 13th. Dr. F. M. Van Tuyl, Mr. Harry Stommel, and Mr. Ralph Holmer accompanied our group. Dr. Van Tuyl explained the geology between Denver and St. Louis during the bus trip. All the students thought the convention profitable and worth the time and expense.

April 22, 1949 (Engineers' Day)

The Society held its luncheon Engineers' Day at the Colorado School of Mines. Dr. M. M. Slotnick presented a paper on "Geophysical Prospecting in the Gulf Coast Regions." His talk was illustrated with slides and the regional gravity map of the southeastern United States made by the Humble Oil and Refining Company. The attendance at this luncheon was 16 guests and 42 members of the Society.

The exhibition of oil paintings from the collection of The Standard Oil Company of New Jersey was not exhibited Engineers' Day as planned. The Standard Oil Company was not able to ship the paintings in time because of the Railway Express strike in New York City. However, we are planning to sponsor this exhibition during the 75th Anniversary of The Colorado School of Mines in September.

Dr. M. M. Slotnick, Dr. L. L. Nettleton, and Mr. Dart Wantland were made Honorary Life Members of the Society for their participation in the Engineers' Day program.

May 5, 1949

At the meeting May 5, officers for the year 1949–1950 were elected as follows:

President, Frank P. Troseth
Vice-President, Howard W. Leaf
Secretary-treasurer, W. J. Busteed

C. W. BOWLBY
Secretary-Treasurer

MINUTES

ANNUAL BUSINESS MEETING

March 14, 1949

The Annual Business Meeting of the Society of Exploration Geophysicists was held in the Gold Room of the Jefferson Hotel, St. Louis, Missouri. The Meeting was called to order by President L. L. Nettleton at 2:00 P.M.

The minutes of the Annual Meeting held in the Silver Glade Room of the Cosmopolitan Hotel, Denver, Colorado, on April 26, 1948, were read by the Secretary and were approved as read.

The report of Dr. Roland F. Beers, Chairman of the Honors and Awards Committee, was read by President Nettleton. No award was made for the year 1948. The report was accepted. Dr. Beers' report is attached and is shown as Exhibit A.

The Editor's report, given by Dr. M. King Hubbert, was read and accepted. This report, which includes that of the Special Reviews Committee headed by Richard A. Geyer, is attached as Exhibit B.

The report of the Program and Arrangements Committee was given by Vice-President Andrew Gilmour who is Chairman of this Committee. His report was accepted and is attached as Exhibit C.

The report by the Student Membership Committee was given by Prof. V. L. Jones, Chairman. This Committee suggested fellowships to be sponsored by the Society. Action on this suggestion was referred to the Joint Council Meeting. The report is attached as Exhibit D.

The report of the Radio Facilities Committee was given by Chairman R. D. Wyckoff. The accomplishments and the organization of the committee were briefly reviewed by Mr. Wyckoff. His report was accepted and is attached as Exhibit E.

Mr. Francis F. Campbell, Chairman of the Distinguished Lecture Committee, advised that whereas no tours could be arranged for 1948 it was thought possible that the idea could be definitely developed during 1949. His report was accepted and is attached as Exhibit F.

In the absence of A. E. McKay, Chairman of the Safety Committee, his report was read by Mr. Cecil H. Green. The Committee feels that although safety is of prime interest, it should not be sponsored by the Society. The report was accepted and is attached, hereto, as Exhibit G.

The Public Relations Committee report was read by George E. Wagoner, Chairman. During 1948 a considerable amount of publicity was originated in this Committee which was published in the various newspapers and trade journals throughout the country. The report was accepted and is attached as Exhibit H.

The Treasurer, E. V. McCollum, gave a report on the membership and the financial condition of the Society. (See attached Exhibit I.) The report was accepted.

The Business Manager, Mr. C. C. Campbell, reviewed the progress made by the Society during the past year and the activities of his office.

In this report it was pointed out that two of the principal factors causing the recent increase in expenses of the Society are:

1. The establishment of a permanent business office. The healthy growth of membership and the publication and distribution of Early Geophysical Papers (1947), Cumulative Index, 1931–1947 (1948) and Geophysical Case Histories, Volume I (1948) have added considerably to the duties performed by the business office.

2. Higher costs of publishing *Geophysics*. Two increases of printing rates of 20% each have added 44% to the cost per page of printing *Geophysics*. Also the number of pages printed has increased 20% since 1946.

Dr. J. P. Schumacher attended the International Geological Congress' 18th Session in London from August 25 to September 1, 1948. Due to the absence of Dr. Schumacher his report was read by President Nettleton. His report was accepted and is attached as Exhibit J.

Mr. Walter Ruska attended the 8th General Assembly of the International Union of Geodesy and Geophysics in Oslo, Norway during August, 1948. This was the first assembly of this Union since the 7th General Assembly which was held in Washington, D. C. in 1929. The report was accepted and is included as Exhibit K.

Dr. E. A. Eckhardt gave his report on the first Annual Meeting of the Board of Directors of the American Geological Institute which was held in Washington, D. C. October 15 and 16, 1948. His report was accepted and is attached as Exhibit L.

President Nettleton briefly reviewed the publication of Early Geophysical Papers, Cumulative Index 1931–1947 and Geophysical Case Histories, Volume I, which have become available to the membership during the past two years. The President extended the appreciation of the Society to the several members who have devoted considerable time and effort to the Case Histories volume.

Dr. Daniel Silverman proposed that a cooperative research organization should be formed to share the cost and other burdens of developing and testing new ideas. Those interested were invited to meet in the Gold Room at 5:00 P.M. upon conclusion of the Technical Session.

Mr. H. Klaus suggested that a committee should be appointed to frame a Code of Ethics for the operation of field parties. Action was deferred to the Joint Council Meeting.

The report of the Nominations Committee was given by President Nettleton, who is Chairman of this Committee. The results of the voting for new officers are as follows:

Number eligible to vote	1446
Number of ballots received	996
Number of ballots disqualified for non-payment of dues	39
Number of ballots disqualified for other reasons	8

RESULTS

For President:	
Andrew Gilmour	486
M. M. Slotnick	456
No vote	7
Vor Vice-President:	
Roy Lay	436
George Wagoner	499
No vote	14
For Secretary-Treasurer:	
Kenneth E. Burg	492
Curtis H. Johnson	437
No vote	20
For Editor to Serve Two Years:	
R. A. Geyer	481
Sigmund Hammer	447
No vote	21
Total	949

Messrs. Andrew Gilmour, George E. Wagoner, Kenneth E. Burg, and R. A. Geyer were, therefore, formally declared elected.

The meeting was adjourned at 3:32 P.M.

E. V. McCollum, *Secretary*

EXHIBIT A. REPORT OF COMMITTEE ON HONORS AND AWARDS

Mr. E. V. McCollum
c/o E. V. McCollum & Co.
515 Thompson Bldg.
Tulsa 3, Oklahoma

Dear Mr. McCollum:

I wish to advise you of the unanimous action of members of the Committee on Best Paper Award of the Society of Exploration Geophysicists which was reached by mail ballot.

The Committee is of the opinion no award should be made for the year 1948.

Yours truly,

ROLAND F. BEERS, *Chairman*

Jan. 7th, 1949

EXHIBIT B. EDITOR'S REPORT

This report for the period, April, 1948, to April, 1949, brings to a close the present Editor's term of office. During this period four issues of *Geophysics*, containing a total of 458 pages of technical material including thirty-seven technical papers and the Patents and Reviews sections, have been edited and gone to press.

During the present term of office the Editor has attempted to formulate and standardize various style conventions so as to bring the style of *Geophysics* into conformity with best modern technical usage. Considerable progress in this direction has been made with a corresponding improvement of appearance and readability. An outline of these conventions will be passed on to the succeeding Editor, who in the course of his experience may wish to add still others.

The new format, involving a change from a print area of $6\frac{3}{4}$ by $4\frac{1}{8}$ to $7\frac{1}{2}$ by $4\frac{3}{4}$ inches per page was put into effect with the April issue. This has resulted in an increase from 430 to 500 words per page, has brought *Geophysics* into the same format as the A.A.P.G. *Bulletin*, and considerably improved the appearance, in addition to appreciably reducing costs for the same volume of printed material.

The Editor again wishes to express his appreciation to Mr. O. F. Ritzmann for his laborious and painstaking compilation of the Patents section, and to the Reviews Committee under the chairmanship of Mr. R. A. Geyer (whose detailed report follows) for their continued cooperation and assistance. A total of twenty articles and books were reviewed during the year by seven different reviewers. Much of this material included difficultly accessible foreign publications from Japan, China, Russia, Sweden, and Switzerland.

A word of appreciation is due Mr. Colin Campbell, the Society's business manager, for his excellent cooperation and handling of the Society's departmental material, and to Mr. C. A. Wiese and his colleagues of Banta Publishing Company for their cheerful and efficient cooperation. Finally, a word of thanks is due to the many contributors of technical articles whose forbearance with the whims of editorial prerogative have been most exemplary.

The one difficulty which has been experienced during the last year has been an insufficient backlog of manuscripts for efficient handling. The tendency has been for authors who present good papers at the annual and sectional meetings to get too busy to write them up for *Geophysics*. It is here suggested that an important function that can be exercised by both local and national program committees is to see not only that good papers are presented at various meetings, but that these also reach *Geophysics* for publication and the general benefit of the membership of the Society.

M. KING HUBBERT

REPORT OF SPECIAL REVIEWS COMMITTEE

During the past year a total of twenty articles and books were reviewed by either members of the Committee or persons suggested by them. Much of the material reviewed included relatively inaccessible foreign references published in China, Japan, Russia, Sweden, and Switzerland. It is hoped that these reviews were of some benefit to the members of the Society and the Chairman

would like to express his appreciation to the members of the Reviews Committee listed below for their cooperation in contributing to the effort.

C. Hewitt Dix	Florence Robertson
Milton B. Dobrin	Noyes D. Smith
Henry R. Joesting	K. R. Weatherburn

The Chairman would also like to thank the following members of the Society who also contributed reviews during this period.

Mona Dennis Guiler	L. L. Nettleton
Hubert Guyod	M. M. Slotnick
A. J. Hermont	M. C. Terry

Their cooperation was obtained in accordance with the policy of requesting reviews upon occasion from those who have a wide background of experience in certain fields of potential review material. This policy served to provide reviews of better quality over a much more diversified range of subjects than could otherwise be accomplished.

RICHARD A. GEYER, Chairman, *Special Reviews Committee*

EXHIBIT C. REPORT OF THE VICE-PRESIDENT

The principal duty of the Vice-President of the S.E.G. is to be responsible for the national meetings of the Society.

Your Vice-President has received very great assistance in arranging the current program from the Regional Program Chairmen: Mr. K. E. Burg, Dallas; Mr. F. F. Campbell, Tulsa; Mr. L. F. Fischer, Shreveport; Dr. Sigmund Hammer, Pittsburgh; Mr. Maynard W. Harding, Los Angeles; Mr. A. A. Hunzicker, Fort Worth; and Mr. J. C. Pollard, Houston; also, of course, from Mr. Colin Campbell, our Business Manager.

Some of the papers have already been presented. The others will be read this afternoon, tomorrow, and Wednesday. Therefore, I feel that anything further I should say about the program at this time would be superfluous.

ANDREW GILMOUR

EXHIBIT D. REPORT OF COMMITTEE ON STUDENT MEMBERSHIP

During the past year seventy-one have been admitted to Student Membership in S.E.G. The total Student Membership as of March 1, 1949 was one hundred and thirty-nine. This is a significant increase of one hundred and four per cent since March 1, 1948.

While there have been no petitions received for new student chapters this year, it is to be noted that a goodly number from St. Louis University have made application for and been admitted to Student Membership. It is to be hoped that this group will continue to grow and petition for affiliation with S.E.G.

Of our two present student chapters, the one at Colorado School of Mines has been by far the most active during the past year. Their total membership consists of some sixty-one members, eighteen of which are student members of S.E.G. The administration of this institution is one hundred per cent behind its geophysics program which is evidenced by the fact that arrangements were made and permission granted for the entire Senior class of geophysics consisting of thirty students to attend the annual meeting held in St. Louis. Several noted geophysicists have appeared on their programs throughout the year. The student chapter at The University of Tulsa continues to enjoy its unique position of being able to attend the regular monthly meetings of the Geophysical Society of Tulsa—a local section of S.E.G. Their present active membership consists of eighteen, five of which were taken in during the past year. All are student members of S.E.G.

A recommendation of the previous committee whereby a method for quicker action on Student Membership applications be adopted, was successfully completed in the design of a special application form for Student Membership. This new form was circulated among the members of the committee,

for additions and suggestions, the final draft of which was approved by the Executive Committee and has thus far proven to be quite an improvement over the older method.

The committee has taken under advisement and careful consideration the possibility of S.E.G. setting up and sponsoring a student scholarship or fellowship fund, the proceeds of which would be granted annually to some worthy student who shows good promise in geophysics. The outcome of the committee's consideration on this proposal has resulted in the following suggestions:

(1) That such a fund should be set up and sponsored by S.E.G.;
(2) That financial assistance for creating the annual stipend of the fund be obtained by soliciting subscriptions of fifty or a hundred dollars each, annually, from the various geophysical contracting organizations and oil companies;
(3) That a page in *Geophysics* be devoted to a display of the list of the then present financial subscribers, together with the nature and purpose of the scholarship fund, and the then present recipient, etc.;
(4) That a special committee be appointed to set up the mechanics and administer the operations of the proposed scholarship or fellowship fund, or, that one or more members of the Council and/or Executive Committee be appointed to work with the Student Membership Committee in selecting a list of recognized and approved educational institutions from which the recipient can make his selection, and, the method and means of annually selecting the recipient of the stipend;
(5) That the scholarship or fellowship be granted annually to some senior or graduate student of geophysics who would otherwise be unable to continue his formal training without such assistance, one who is not receiving financial support from the government or otherwise;
(6) That the annual stipend of the scholarship be $800 to $1000;
(7) That in the event the response from industry by way of subscriptions should prove adequate, that two such scholarship or fellowship funds be established, one for Senior students, and the other at the graduate level.

It has also been suggested that such a scholarship or fellowship be designated as the Donald C. Barton Fellowship.

It is earnestly recommended that the Council and the new committee give careful consideration to this proposal and the above suggestions to the extent that the proposal will result in a working reality.

It is also recommended that the new committee devise a means and method whereby the story of geophysics may be taken to colleges and universities in which no courses are offered in geophysics.

V. L. JONES, *Chairman*
D. S. HUGHES
E. A. HODGSON
H. V. W. DONOHOO
SILVAIN PIRSON
LOUIS SLICHTER
C. H. DIX
J. C. MENEFEE
RALPH C. HOLMER

EXHIBIT E. REPORT OF RADIO FACILITIES COMMITTEE

The following represents a very brief resume of the organizational setup and activities of your Radio Facilities Committee appointed at the 1948 Annual Meeting, Denver, Colorado.

Organization

Committee Roster

Chairman—R. D. Wyckoff

Members—Six chairmen of District Committees

California District

Bart W. Sorge, Chairman
Dean Walling
H. R. Thornburgh
R. C. Dunlap, Jr.

Dallas District

John P. Woods, Chairman
Pat Haggerty
Early Shook
Frank Kennedy
J. P. Woods

Fort Worth District

V. Robert Kerr
Robert E. Klabzuba
S. E. Van Steenbergh

Houston District

W. M. Rust, Chairman
O. B. Hocker
S. Kaufman
H. E. Banta
F. F. Reynolds

Tulsa District

Dan Silverman, Chairman
E. M. McNatt
J. E. Hawkins
J. A. Sharpe
W. T. Born
A. J. Hintze

Shreveport District

Richard Brewer, Chairman
J. E. Walker
Herbert A. Morriss
Glenn J. Baker

As outlined at the organizational meeting at Denver, it is the function of this SEG committee to provide an expeditious means for determining the consensus of the entire geophysical industry concerning frequency allocation matters. On this basis, representations before the Federal Communications Commission may be made on behalf of the industry as a unit, presenting a united front as required rather than individual and possibly discordant views. Your committee believes that this aim has been accomplished.

API Affiliations

Further, as outlined at the Denver meeting, actual representations before the FCC are made through the American Petroleum Institute, Central Committee on Radio Facilities. This API Committee handles the radio services in all phases of the petroleum industry represented by subcommittee covering Maritime, Pipeline, Production, and Geophysical use of radio. Its organization is as follows:

API Central Committee on Radio Facilities of the Division of Transportation API

Chairman—F. W. Littell
Vice Chairman—J. A. Polhemus, Jr.
Secretary—B. H. Lord

Committee on Law and Regulation

Chairman—Joseph E. Keller, Attorney
Vice Chairman—Harry L. Cornell

Committee on Use of Radio in Production

Chairman—O. B Hocker
Vice Chairman—D. H. Clewell

Committee on Pipeline Use of Radio

Chairman—C. B. Lester
Vice Chairman—F. T. Clark

Committee on Radio Engineering

Chairman—Joseph H. Wofford
Vice Chairman—E. M. Shook

Committee on Radio Frequency Coordination

Chairman—R. M. Slough
Vice Chairman—H. A. Rhodes

Committee on Maritime Use of Radio

Chairman—Harry L. Cornell
Vice Chairman—Robert Gray

Committee on Geophysical Use of Radio

Chairman—R. D. Wyckoff
Vice Chairman—W. M. Rust, Jr.
Member—Dan Silverman

It was agreed by the API Central Committee at the time of its organization that the roster of the latter Committee will comprise members of the SEG Radio Facilities Committee as has been the case during 1948–1949. Since the actions by this Subcommittee are guided by the deliberations of the entire SEG group, you may be assured that the geophysical industry is properly represented.

Your attention is also called to the fact that proposed new rules of the Federal Communications Commission aim to consolidate all industrial mobile radio facilities into one group, including geophysics. In this proposed setup which is certain of adoption, geophysics would be included as a part of the petroleum industry. Thus our association with and representation through the API committee is not only convenient but a practical necessity. Furthermore, through this arrangement your committee is provided with the legal talent necessary in FCC proceedings, being represented by Mr. Joseph E. Keller, Washington, D. C., Attorney for the API.

Activities

Very soon after the organization of the Committee, impending FCC Hearings forced an immediate canvass of the group to determine opinions of the industry regarding frequency allocation requirements. This was accomplished through representatives meeting with the District Committees. As a result of these deliberations, it was possible to prepare a brief "Study of Geophysical Frequency Allocations" outlining the communications and radio-location facilities required by the industry and presenting a united front on these requirements.

Through the API, your committee participated in the FCC Hearings, July 19, 20, and 21, 1948, (Docket 8989) involving applications of the Seismograph Service Corporation and Frost Geophysical Corp., Tulsa, for Class II experimental licenses to operate phase-comparison, radio-location equipment. At this Hearing, the needs of the industry for phase-comparison, Radar and Shoran methods were presented.

Again in October, 1948, hearings were held in Washington (Docket 9018) covering the proposed new rules under which geophysical service would be included within the petroleum industry service under allocations covering the entire Industrial Mobile Services.

Details of the proposed allocations may be obtained from the Federal Register, Vol. 13, No. 122, of June 23, 1948, where, under Petroleum Radio Service (p. 3430) proposed frequency assignments are listed. These include the following on a shared basis with Forest Products Service:

25.02–25.32 mc—16 channels
33.18–33.38 mc— 6 channels
48.46–48.98 mc—27 channels
49.00–49.24 mc—13 channels

In addition, the proposed new rules include under Special Industrial Radio Service certain channels which may be available to Petroleum Service on adequate showing of need. Included in this list are the following frequencies for base and mobile stations for all types of mobile service operation which are of special interest to geophysical service:

1602 kc
1628 kc
1652 kc
1676 kc
1700 kc
2292 kc
4637.5 kc
152.99 mc–158.31 mc—11 channels*

We have requested the exclusive use as in the past of the five channels 1602–1700 kc for geo-

* We have requested that these channels be made available to geophysical service without the need for special showing.

physical service, and have made a special effort to stress the importance of these low frequency channels in petroleum exploration.

It will be noted that under the new rules wherein geophysics is included as a part of Petroleum Service and channels are shared also with Forest Products Service, close coordination will be required to avoid interference. Steps have already been taken with the API Committee to get up means whereby this may be accomplished both within the industry and in collaboration with the Forest Products group.

Federal Communications Commission Actions
Radio-location Service

The Federal Register, December 21, 1948, published the provisions of the adopted Part 2 of the Commission's Rules. These Rules make available for radio-location and radio-navigation devices, such as Shoran and Radar, the following frequency bands:

†2450–2500 mc	5460–5650 mc
2900–3246 mc	9000–9300 mc
3266–3300 mc	9320–9500 mc
5250–5440 mc	

† (Use of this band by radio-location devices is subject to provision that no interference is caused to radio-navigation service.)

We were not successful in obtaining frequencies in the 900 mc region (medical and industrial devices), because these bands have been allocated to broadcasting. Further allocation proceedings would be required to reopen this question.

Phase-comparison Method

Temporary allocation of the band 1750–1800 kc was made February 24, 1949, for radio-location service for a period of six months subject to continuance for additional periods, if necessary, but subject to earlier cancellation at the discretion of the Commission. This temporary allocation is strictly limited to radio-location service for petroleum exploration in the Gulf of Mexico. This allocation is, in effect, provision for experimental operation of phase-comparison methods to determine the practicability of such methods in view of the Commission's recognition of the need for such non-line-of-sight location devices. Based on results obtained, the FCC may at some later date consider permanent allocations for such purposes.

General Geophysical Services

According to the best available information, final allocation of adequate channels for the Industrial Mobile Services including geophysical would probably have been made by now. However, any such action by the Commission has been delayed and the problem confused pending a court hearing on renewal of a certain broadcast license involving a portion of the proposed mobile service frequencies. Denial of renewal of this license by the FCC led to issuance of an injunction by the U. S. Court of Appeals, December 31, 1948, granting a temporary stay of the Commission's non-renewal action.

Thus it is impossible to say at this time when final action may be taken on the adoption of the new allocations outlined above.

In conclusion, it may be said that the Commission is cognizant of and fully appreciates the importance of providing the geophysical industry with adequate radio facilities. But it is faced with many problems in this complex matter of frequency allocation in which not only domestic but international agreements are involved. We may end out with losses that we can ill afford, but you may be assured that it has not been due to any failure on the part of the geophysical industry to make known its needs. Moreover, the Commission has lent a sympathetic and understanding ear to our requests for adequate facilities to meet these needs.

R. D. WYCKOFF, *Chairman*

EXHIBIT F. REPORT OF THE DISTINGUISHED LECTURE COMMITTEE

Dr. L. L. Nettleton appointed the Distinguished Lecture Committee of the Society of Exploration Geophysicists in October, 1948. Francis F. Campbell of Amerada Petroleum Corporation, Tulsa, became chairman; Mr. Richard A. Geyer of Humble Oil & Refining Company, Houston, and Mr. John H. Wilson of Independent Exploration Company, Fort Worth, became members. Mr. John L. Ferguson who developed the Distinguished Lecture Committee of the American Association of Petroleum Geologists has served as advisor to the chairman.

During November the chairman met with the members of the committee. It was agreed: first, that not more than two tours should be attempted in one lecture season; second, that it would be preferable to have a research or academic speaker, rather than one from a commercial organization, for the first speaker; third, to select a panel of lecturers rated from the standpoint of speaking ability and knowledge of subject matter; and fourth, to contact the local sections of the S.E.G. in order to determine the extent of their interest and to ascertain which of the speakers on the panel they preferred.

The response of the local sections to these inquiries was favorable but indefinite. Therefore, in order to make the matter specific, the chairman proposed a tour by Dr. Merle A. Tuve, Director of the Department of Terrestrial Magnetism, Carnegie Institute, Washington, D. C., speaking on the seismic experiments across the Appalachian Mountains conducted by this organization. The proposed tour was suggested for the latter part of April, 1949, and descriptive material was sent to the six S.E.G. sections in December. By the end of January commitments to participate in the tour had been received from Tulsa, Houston, Dallas, Fort Worth, and the Pacific Coast. Although no response was received from the officers of the Ark-La-Tex Geophysical Society, a member of that organization indicated that the society would be interested in participating. An invitation was extended to Dr. Tuve on February 1, but he was unable to accept because of the pressure of other duties. Since there remained insufficient time to canvass the sections and invite another speaker before the close of the lecture season, no further action has been taken.

In comparing the work of the committee with that of the A.A.P.G. Distinguished Lecture Committee, it should be remembered that the A.A.P.G. Committee serves some forty local geological societies and educational institutions. Thus it is in a position to secure a definite commitment from a speaker and then ask its clientele to participate. Since the speaker is usually limited to some fifteen appearances anyway, there is always a sufficient number of participants to make the tour a success. By contrast, the Distinguished Lecture Committee of the S.E.G. felt that this year it must secure commitments in advance from all of the local sections before a speaker for a proposed tour could be approached. This position may be modified next year. Another remedy for this situation which the committee is considering is to expand the list of possible participants by including educational institutions such as the California Institute of Technology, the Colorado School of Mines, and St. Louis University.

The committee received generous cooperation from the officers of the local sections and believes that with a continuance of this spirit of cooperation at least one lecture tour can be arranged for the 1949–50 season. Therefore, the committee recommends that the Distinguished Lecture Committee of the S.E.G. should be continued and requests that it be made a standing committee in order that commitments made during one fiscal year may have legal standing for the following year.

FRANCIS F. CAMPBELL, *Chairman*

EXHIBIT G. REPORT OF SAFETY COMMITTEE

Dr. L. L. Nettleton, President of the Society of Exploration Geophysicists, appointed a Safety Committee, June 30, 1948, as directed by the motion authorizing such a committee by the Council at the national meeting in Denver in 1948. This motion included the direction, "The president . . . appoint a Safety Committee which would report to the Executive Committee on its recommendations covering safety measures which the Society would back and that the Executive Committee would take appropriate action as was deemed necessary . . . ." The sense of this motion was that local

sections will digest the information on safety available in the areas. A central Committee would coordinate this information and report it to the Executive Committee.

This Committee, after due consideration of all angles and after discussion with a representative number of members of each local section, reached the unanimous opinion that the Society should not sponsor, endorse, or otherwise enter into, the establishment or creation of a "safety code" in fact or suggested.

The basis of this recommendation rests almost entirely on the premise that this subject is not suitable to a Society whose object is to promote the science of geophysics especially as it relates to exploration and research, to foster the scientific interests of geophysicists, and to maintain a high professional standing among its members.

In arriving at the above decision, many phases of the subject were considered. These questions may be of some interest and are made a part of this report.

1) Safety, although of real interest to a majority of the individual members, is operational in nature, and, therefore, a more proper question for industry and industry sponsored organizations such as the National Safety Council.

2) Some concern was expressed by a few of the members that a safety code sponsored by the Society might in some way, directly or indirectly, involve the Society in legal entanglements. In the opinion of the majority of the Committee, this possibility seemed very, very remote.

3) The Society "tax exempt status" was considered, and it is almost certainly true that an activity such as the safety code would have no bearing on the Society's tax exempt status, since the Society is not carrying on business for profit and since no part of the net earnings of the Society inures to the benefit of any private shareholder or individual.

A. E. McKay, *Chairman*
W. D. Baird
John W. Mathews
A. J. Hintze
F. F. Reynolds
John A. Lester
L. H. Wells

EXHIBIT H. REPORT OF THE PUBLIC RELATIONS COMMITTEE

Following the annual business committee meeting of the Society of Exploration Geophysicists held in Denver, in 1948, the following Public Relations Committee was appointed:

Geo. E. Wagoner, Chairman
Paul L. Lyons, Vice Chairman
Howard E. Itten
W. G. Smiley, Jr.
Phillips J. Kempsky
B. B. Burroughs
H. M. Thralls
Earl W. Johnson
J. W. Horn

Members of the committee are chairmen of the Public Relations Committees of the local sections. The purpose of the committee is to assist the Society in obtaining its rightful recognition and its separate identity mainly by means of guided publicity.

The following accomplishments were made by the committee during the year 1948–1949.

1. A system of distribution of press releases was inaugurated. News items of S.E.G. are sent to the Vincil System, of Tulsa, Oklahoma. The system provides for immediate mailing of press releases to 28 newspapers of oil cities, to the United Press, to 5 oil journals, to 5 technical publications, to the U. S. Geological Survey Library, to Society officers, to members of the Public Relations Committee, and to local section presidents and secretaries.

2. A code of 17 suggestions was established to promote and guide the activities of the Public Relations Committee.

3. A history of the S.E.G., together with a paralleling history of geophysical exploration for oil, was published as a pamphlet. The history was distributed at the International Petroleum Exposition at Tulsa May 15–22 and was sent to all members of the Society. Copies of the history are sent to all new members of S.E.G.

4. A display booth was set up in the Science Building at the International Petroleum Exposition at Tulsa, May 15–22, in a joint action with the Publicity Committee of the Geophysical Society of Tulsa.

5. Special emphasis was placed on gaining publicity for the two books of the Society published during the committee's tenure. The volumes were the "Cumulative Index" and the first volume of "Geophysical Case Histories." As a result, favorable reviews were published in several newspapers and journals. Increased sales were directly attributable to these reviews.

6. Arrangements were made for publication of E. A. Eckhardt's paper, "Geophysical Activity in the Oil Industry in the United States in 1947," by *The Oil & Gas Journal* in its issue of September 30, 1948, which preceded publication of the paper in the October *Geophysics*. Thus this timely article was made available to the oil industry in general, together with appropriate published acknowledgment to the S.E.G. The committee suggests such publication of geophysical activity be made an annual feature.

7. Arrangements were made for free inclusion of a page in *The Geophysical Directory* for 1949 containing a statement of the Society's aims and a list of national officers, as well as officers of sections.

8. Special effort was made to obtain publication of acceptance notices of the regional and the annual meetings of the Society.

9. Publicity was secured for the candidates for national offices. Pictures of the candidates were provided for all newspapers in the home cities of the eight candidates, together with appropriate biographical data.

10. Abstracts of papers to be presented at the March meeting at St. Louis were provided to *The Oil & Gas Journal*, to *Oil World*, and to *World Petroleum*.

11. A set of questions was drawn up for answer by leading geophysicists. The questions pertain to the use and progress of geophysical methods and to the effectiveness of exploration for oil. Statistical results of the survey will be used to compose worthwhile publicity articles that will be of service to the oil industry. A preliminary O.K. was secured for this project from the Executive Committee at the Dallas regional meeting.

12. Copies of reports of local Public Relations Committees are attached.

GEO. E. WAGONER, *Chairman*

EXHIBIT I. TREASURER'S REPORT

The comparative statement of the financial position for 1947 and 1948 is shown in Table I. Whereas, the assets of the Society show a healthy current position, the decrease of $4,313.00 in the surplus account forecasts trouble in the next two to three years unless remedial steps are taken.

Operations (Table II) shows that the main increase in expenses has been the maintenance of a business office, which began full scale operations June 1, 1948, and increase in cost of publishing *Geophysics*.

The membership of the Society has more than doubled since 1940. Such a growth would ordinarily ease the financial pains with everything else remaining equal. However, other factors have changed, such as

1. Increased publishing costs of *Geophysics*.
2. The size of *Geophysics* has increased from 562 pages in 1940 to 896 pages in 1948.
3. A larger business office has become necessary because of
   a. Increase in Membership.

b. Special Publications.
c. Formation of Local Sections.
d. Student Memberships.

During 1948 the advertising rates and number of advertisers has been increased. A raise in membership dues has been given considerable attention by the Executive Committee. Such a move seems the only remedy.

The Report on Membership is shown in Table III.

TABLE I. FINANCIAL POSITION

	DECEMBER 31		Increase or decrease
	1948	*1947*	
Assets—			
Cash	$ 7,113	$10,315	*$3,202*
Accounts receivable, less reserve	1,575	780	795
Inventory of publications	2,989	1,142	1,847
Investments	18,880	18,880	
Office equipment, less reserve	857	565	292
	$31,414	$31,682	$ *268*
Liabilities—			
Current liabilities	$ 779	$ 581	$ 198
Deferred income	6,381	2,534	3,847
Surplus	24,254	28,567	*4,313*
	$31,414	$31,682	$ *268*

TABLE II. OPERATIONS

	1948	*1947*
Income—		
Membership dues	$ 8,896	$ 7,630
Advertising, subscriptions, etc., relating to *Geophysics*, less discounts	10,860	9,717
Sales of Early Geophysical Papers	1,288	2,755
Sales of Cumulative Index	1,563	
Interest received	255	260
	$22,862	$20,362
Expenses and publications costs—		
Operating expenses	$13,343	$ 8,998
Publications costs		
Geophysics and reprints	10,412	8,051
Early Geophysical Papers	1,142	2,602
Cumulative Index	2,278	
	$27,175	$19,651
Net *loss* or income	$ *4,313*	$ 711

TABLE III. REPORT ON MEMBERSHIP

	Number of Members at Year End			
	1948	*1947*	*1946*	*1945*
Active Members	1,446	1,302	1,178	1,072
Associate Members	271	220	186	183
Student Members	102	68	12	5
Honorary Members (Living)	3	3	3	3
Totals	1,822	1,593	1,379	1,263
Increase over prior year	229	214	116	130

The report of the independent accountants for the year 1948 follows:

PRICE, WATERHOUSE & CO.

1221 Locust Street
St. Louis 3
March 15, 1949

To the Executive Committee,
Society of Exploration Geophysicists,
Tulsa, Oklahoma.

We have examined the balance sheet of the Society of Exploration Geophysicists as at December 31, 1948 and the statement of net loss for the year then ended. Our examination was made in accordance with generally accepted auditing standards, and accordingly included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances, except that as instructed we did not apply the customary procedure of confirming receivables by direct communication with debtors.

The office staff is too small to permit the establishing of an effective system of internal accounting control; therefore, we extended our tests of the transactions beyond those necessary where an adequate system is in force. While we did not make a detailed audit of all of the transactions, we compared the recorded cash receipts in totals with deposits shown on the bank statements for the year and examined paid checks, cash vouchers, and other supporting data for all disbursements.

In our opinion, subject to the foregoing comments relating to the confirmation of receivables and to the system of internal accounting control, the accompanying balance sheet and statement of net loss present fairly the position of the society as at December 31, 1948 and the results of its operations for the year, in conformity with generally accepted accounting principles applied on a basis consistent with that of the preceding year.

PRICE, WATERHOUSE & CO.

SOCIETY OF EXPLORATION GEOPHYSICISTS
BALANCE SHEET—DECEMBER 31, 1948

ASSETS

Cash		$ 7,112.79
Accounts receivable:		
Advertising, subscriptions, and special publications	$ 1,566.84	
Membership dues	608.58	
	$ 2,175.42	
Less—Reserve for bad debts	600.00	
		1,575.42
Inventory of publications, at lower of cost or selling price (see note)		2,989.43
Investments, at cost:		
Farm and Home Savings and Loan Association of Missouri—fully paid investment certificate	$ 5,000.00	
United States Savings Bonds	13,880.00	
		18,880.00
Office equipment	$ 1,134.87	
Less—Reserve for depreciation	278.00	
		856.87
		$31,414.51

LIABILITIES

Accounts payable		$ 742.98
Federal insurance contributions tax		36.06
Deferred income:		
Membership dues	$ 898.00	
Geophysical Case Histories	4,390.00	
Subscriptions to and advertising in *Geophysics*	1,093.56	
		6,381.56
Surplus:		
Balance, December 31, 1947	$28,567.20	
Net loss for the year	*4,313.29*	
		24,253.91
		$31,414.51

Note—

This balance sheet does not reflect the inventory of back numbers and reprints of *Geophysics*, the cost of which was charged off at the time of publication.

SOCIETY OF EXPLORATION GEOPHYSICISTS
STATEMENT OF NET LOSS FOR THE
YEAR ENDED DECEMBER 31, 1948

INCOME:			
Membership dues		$ 8,896.00	
Publications:			
Advertising	$5,961.76		
Subscriptions	2,999.79		
Back numbers	1,604.97		
Reprints	669.08		
Discounts allowed	*375.36*		
Early Geophysical Papers	1,287.50		
Cumulative Index to *Geophysics*	1,563.85		
		13,711.59	
Interest received		255.00	
			$22,862.59
EXPENSES AND PUBLICATION COSTS:			
Salaries:			
Business manager		$ 3,450.00	
Office assistant		2,040.32	
Commissions:			
Advertising—business manager		805.11	
Advertising—agencies		715.57	
Subscriptions—agencies		126.23	
Office rent		840.00	
Stationery and office supplies		1,882.68	
Postage		797.28	
Telephone and telegraph		338.00	
Traveling		96.46	
Annual and regional meetings		403.82	
Auditing		301.56	
Depreciation of office equipment		149.57	
Advertising		447.49	
Federal insurance contributions tax, including $455.37 for prior years		519.36	
Provision for bad debts		254.50	
Miscellaneous		175.66	
		$13,343.61	
Publication costs		13,832.27	
			$27,175.88
Net *loss*			$ *4,313.29*

EXHIBIT J. INTERNATIONAL GEOLOGICAL CONGRESS 18TH SESSION LONDON, AUGUST 25–SEPTEMBER 1, 1948

The 18th Session of the International Geological Congress was held in London between August 25 and September 1, 1948. The total registrations from approximately 77 countries numbered 1746.

The headquarters of the Congress was in the Geological Survey and Museum and the sessions were held in the Albert Hall, Imperial Institute and the Royal School of Mines.

The 389 technical papers presented were divided among 12 sections of which Section D, The Geological Results of Applied Geophysics, listed 27 papers.

A volume of titles and abstracts was presented to the members of the Congress, and the papers will be published in a Report some time before August, 1952, at which time the next Session of the Congress will be held in Algeria.

Several papers were presented on tectonic interpretation by means of geophysical data, such as J. Goguel, The Geology of the Peri-Alpine Depressions of the Saone and the Rhone Basins (France) as shown by geophysical prospecting (gravimetric, telluric and electrical well logging methods); F. Montandon, Northwest Alpine Fractures and Seismic Zones (Switzerland); N. Oulianoff, Seismology and Alpine Basement Structure (Switzerland); H. W. Straley, Is the Basement Complex Involved in Appalachian Folding? (U.S.A.); H. I. S. Thirlaway and A. H. Cook, Recent Observations of Gravity in Wales and the Borders (Great Britain).

The Association of African Geological Surveys being in session during the Congress, many papers were devoted to the geology of Africa. Geophysical research conducted on that continent was reported on in the following papers: A. Frost and O. Weiss, Geological Results of Geophysical Prospecting in the Discovery of the Odendaalsrust Goldfields in the Orange Free State of the Union of South Africa; J. J. Breusse, Electrical Prospecting and Hydrological Problems in the Dakar Peninsula (French West Africa); I. de Magnee, Delineation of a Kimberlite Pipe by Geoelectric Methods in the Belgian Congo; L. Migaux, Comparison between Telluric and Gravimetric Surveys in Morocco and in Aquitania (France); G. Castany submitted three papers on geoelectric research in Tunisia.

Other papers on gravimetric surveys were submitted, such as V. E. Barnes, R. W. Mathis and F. Romberg, Gravity Prospecting for Lead and Zinc, New Mexico; and W. Bullerwell, A Gravitational Survey Over a Concealed Portion of the Warburton Fault, near Lymm, Cheshire (Great Britain).

H. Reich presented three geophysical maps at a scale of 1:500,000 showing magnetic, gravimetric and seismic surveys in northwestern Germany, and a paper by O. Heerman discussed the application of seismic reflection methods to salt dome structures in the northwestern German Permian Basin.

U.S.S.R. geophysicists presented papers on the Airborne Magnetometer and on Gravity Anomalies of the Eastern European Platform.

Other papers were read on seismic and magnetic methods, radioactive and earth resistance measurements and supersonic vibration experiments. A complete list of titles and abstracts will be published in a forthcoming issue of *Geophysics*.

J. P. SCHUMACHER,
S.E.G. Delegate

EXHIBIT K. REPORT ON THE EIGHTH GENERAL ASSEMBLY OF THE INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS

The Eighth General Assembly of the International Union of Geodesy and Geophysics was held at the University of Oslo in Oslo, Norway, on August 17 to August 28, 1948. It was the first meeting of the Union since the outbreak of World War II, the Seventh General Assembly having been held in Washington in 1929. Over five hundred delegates representing thirty-seven countries attended the assembly. Sixty-seven delegates were present from the United States.

The host of the Assembly was the Norwegian National Committee of the UGGI, and they, to-

gether with Dr. Halvor Solberg and Major P. A. Grinaker, deserve a great deal of credit for the fine preparations made for the assembly.

The administrative meetings of the Union Executive Committee, the Union Council, and the Union Finance Committee occupied the first two days. The formal opening of the General Assembly was held on August 19 at the Aula of the University in the presence of their Majesties, King Haakon VII and Prince Olav of Norway. The delegates were welcomed by Dr. Halvor Solberg, President of the Norwegian National Committee, Foreign Secretary Halvard M. Lange, of the Norwegian Government, and Vice-Chairman Mr. Brynjulf Bull, of the Town Council of Oslo. The opening address was given by Dr. N. E. Norlund, Acting President of the UGGI.

The scientific meetings were subdivided into departments for geodesy, seismology, meteorology, terrestrial magnetism and electricity, physical oceanography, vulcanology, and scientific hydrology.

The large number of scientific papers and national reports presented required an extremely tight schedule and made it necessary for meetings to be held parallel in various lecture halls at the University. Papers were read in English, French and Norwegian, but quite a number of additional languages could be heard during the discussions. My interest being principally in terrestrial magnetism, I attended most of the meetings of the section "Terrestrial Magnetism and Electricity," which alone had over 100 scientific papers scheduled. Since Dr. Fleming could not be present, Dr. J. Wallace Joyce, Secretary and Director of the Central Bureau of the International Assembly of Terrestrial Magnetism and Electricity, read Dr. Fleming's address "Some Needs and Challenges of Geomagnetism." Professor J. Coulomb of the University of Paris and Dr. Joyce presided over the magnetism meetings.

Many papers were presented which demonstrated the broadness of the interests of the various delegates. Papers covered various types of magnetic surveys and instruments, including experiments of the United States and English governments with the airborne magnetometer, interrelation of solar activity and terrestrial magnetic phenomena, physical phenomena of the upper atmosphere and ionosphere, aurora, atmospheric electricity, the origin of the earth's magnetic field, and many other subjects. The correlation of observations between the various geomagnetic observatories, such as substitution of the C Index by the K or Three-Hour Index for magnetic activities, and other standardization of intercomparison of observations were also discussed.

Twenty-one Resolutions were submitted and approved at the final General Assembly of the Union. Three resolutions in geodesy called for cooperation with the International Astronomical Union in establishing closer latitude, longitude and time controls. The importance of more accurate gravity base stations for the principal gravity survey nets was recognized, and the use of modern gravity meters to obtain greater accuracy between check points was recommended. Additional gravity surveys were called for to determine the shape of the earth and to determine transoceanic profiles of all oceans. Two resolutions on seismology called for re-establishment and modernizing of seismic stations in India, LaPlata, Tananarive, Tamanrasset, Perth, Apia, China, Melbourne, Adelaide, Suva, Mauritius and Johannesburg and other parts of the world. It called for free telegraphic transmission of seismic data to the "Bureau Central de Seismologie."

Ten resolutions of the section "Terrestrial Magnetism and Electricity" called for new geophysical observatories in Northern Sweden, Finland, Italy, Southern India, Belgian Congo, The French Colonial Possessions and Spain. The establishment of a new and extended geomagnetic observatory and laboratory for the existing observatory of Cheltenham, Maryland and the decision to establish a center of geophysical studies in Belgium was welcomed. It was recommended that hydrographic services should consider the construction of nonmagnetic vessels to extend ocean magnetic surveys in cooperation with Great Britain. Two resolutions in Physical Oceanography and four resolutions in Scientific Hydrology were passed.

During the assembly quite a number of social events and receptions were arranged to welcome the delegates and guests. The officers and principal delegates of the Union were received at the Royal Palace by the King of Norway. The Norwegian National Committee held a reception at the Geographic Institute and the City of Oslo at Akerhus Castle. The American delegates were received at

the American Embassy. An excursion to Lillehammer was made on Sunday, August 22. After the closing of the assembly, trips to Bergen and other scenic and interesting areas of Norway were arranged.

The ninth General Assembly will be held in Brussels, Belgium in 1952.

WALTER RUSKA, *S.E.G. Delegate*

EXHIBIT L. THE AMERICAN GEOLOGICAL INSTITUTE

The first annual meeting of the Board of Directors of the American Geological Institute was held in Washington, D. C., October 15 and 16, 1948. At the convention in Denver a year ago, you elected as Directors to represent your Society on the Board, Dr. L. L. Nettleton, for a period of two years, and E. A. Eckhardt, for a period of one year. Your Society was represented at the organization meeting by your one-year Director.

The Board elected the following officers:

President	A. I. Levorsen
Vice President	W. B. Heroy
Secretary-Treasurer	Earl Ingersen

and authorized the following standing committees and defined their functions:

Education	Public Relations
Personnel	Government Relations
Publications	Finances
Research Information	

The A.G.I. Constitution provides that Directors be designated for a period of two years and that a year be construed as the period extending from the close of one annual meeting to the close of the next. This leaves the term of your one-year Director somewhat in doubt. The Society must decide whether it expired at the close of the first annual meeting or whether it will expire at the close of the second annual meeting. In any event the Society at this time will have to designate a Director for a two-year term and take similar action each year.

It seems very probable that some of the burden of supporting the A.G.I. will inevitably fall on your Society and your representative recommends that this probability be taken into consideration in making the fiscal plans for the years immediately ahead. I am unable at this time to estimate what the amount should be.

The initial steps toward the formation of the A.G.I. were taken with considerable enthusiasm. It is my belief that there is important work to be done by an organization which represents all geologists and their professional associations. The initial meeting of the Institute was held five months ago and, as far as I know, the next one is scheduled to be held about eight months hence. This does not indicate much vitality. The enthusiasm seems to have worn itself out in overcoming the many obstacles which had to be overcome before A.G.I. could become established. I do hope that, in spite of all this, A.G.I. may yet become a vigorous standard bearer for all geologists and all geology.

E. A. ECKHARDT, *Director A.G.I. representing S.E.G.*

ANNOUNCEMENTS

EARLY GEOPHYSICAL PAPERS (1947)

The greatly increased demand for the volume, *Early Geophysical Papers*, has depleted the supply of this publication, and it has been out of print since December, 1948. Members and subscribers needing this volume are urged to advise the Business Manager immediately. As soon as 500 orders have been received, it will be possible to reproduce the volume for sale at the original price of $5.00 to members, and $6.00 to all others. Address all inquiries to the Society at Box 1614, Tulsa 1, Oklahoma.

SWEDISH GEOPHYSICAL SOCIETY

The Swedish Geophysical Society, founded in 1920 to promote geophysical research and Scandinavian as well as international collaboration in geophysics, has recently initiated publication of a quarterly journal, *Tellus*. This publication is made possible through a grant from the Swedish government. Each issue will contain 48 to 64 pages, the page size being 179×250 mm. While articles may be English, French, or German, it is interesting to note that the initial issue was entirely in English. In line with the pre-eminence of Scandinavian geophysicists in meteorological and oceanographic fields of investigation, the initial issue contains four meteorological papers by T. Bergeron, E. Palmen, A. Nyberg, and C. G. Rossby, an article on the geochronology of the deep ocean bed by H. Pettersson, and a paper on recent inopheric measurements in Lappland by O. Rybeck.

The subscription price is $6.00 per year. Communications relating to manuscripts and subscriptions may be addressed to the Editor of *Tellus*, Fridhemsgatan 9, Stockholm, Sweden.

PENNSYLVANIA STATE COLLEGE
DIVISION OF MINERALOGY AND PETROLOGY

The Pennsylvania State College Division of Mineralogy and Petrology at State College, Pennsylvania, announces the presentation of new graduate option and research in the field of sedimentology, electron microscopy, and experimental silicate petrography. Provisions are made for two full-time research assistantships and four half-time graduate assistantships during the coming academic year.

CHANGES OF ADDRESS FOR *GEOPHYSICS*

Corrections and additions to the mailing list for *Geophysics* are forwarded to the printer on the first day of the month in which an issue is published. Members and subscribers are urged to notify the Business Office (Box 1614, Tulsa 1, Oklahoma) before that date to insure shipment of *Geophysics* to the correct address.

S.E.G. REGULATIONS REGARDING THE RELEASE OF TECHNICAL PAPERS

Upon proper application, the Business Manager may allow advance reproduction of "Titles and Abstracts for Any and All Papers Comprising the Program for an Annual, Regional or Local Section Meeting," provided that due acknowledgment is given.

Papers accepted for publication in *Geophysics* are the property of the Society. Members desiring prior publication of such papers in trade journals, or elsewhere than in *Geophysics*, should submit to the Business Manager one complete copy of the paper and the illustrations, together with the name of the periodical in which publication is desired. Papers printed in trade journals or elsewhere without having been submitted to the Business Manager are not eligible for publication in *Geophysics*.

Upon receipt of such request, the Business Manager will forward the copy of the paper in question to the Editor for examination. Release may be obtained upon joint approval of Editor and Business Manager, subject to acknowledgment to the Society and mention of the particular S.E.G. meeting where the paper was first presented.

Papers which have already appeared in *Geophysics* may be released by the Business Manager, subject to acknowledgment of *Geophysics*.

Popular versions of technical papers by trade journal editorial staffs may be permitted before publication in *Geophysics* by permission of original author (or authors) and Business Manager, subject to acknowledgment of the Society and mention of the first S.E.G. meeting where original paper was presented.

PUBLICATION OF PAPERS WHICH HAVE BEEN PRESENTED AT MEETINGS OF THE SOCIETY AND ITS LOCAL SECTIONS

Authors of papers which have been presented at meetings of the Society who desire publication in *Geophysics* are asked to forward their manuscripts to the editor as soon as possible. For guidance in preparing manuscripts for publication, see page 2 of this issue. More detailed instructions will be found in "Preparation of Manuscripts for Publication in *Geophysics*," by L. L. Nettleton, *Geophysics*, Vol. X, No. 3 (July, 1945).

PERSONAL ITEMS

ALEXANDER DUESSEN, consulting geologist, announces removal of his office from 1006 Shell Building to Room 413 Commerce Building Addition, Houston 2, Texas.

O. F. VAN BEVEREN is now exploration superintendent of the Northern District for Standard Oil Company of California. His address is Box 1200, Bakersfield, Calif.

JOHN H. HODGSON, formerly assistant professor of geophysics at the University of Toronto, is now in the seismological division of the Dominion Observatory at Ottawa, Ontario, Canada.

JOHN F. GALLIE, former Business Manager of the Society, has resigned his position as senior, geologist with the Cabot Carbon Co. He has joined Ralph E. Davis as consulting geological engineer and may be addressed at 1434 Commerce Building, Houston 2, Texas.

G. D. GIBSON, party chief and partner in the Oklahoma Geophysical Company, has established an office in Sweetwater, Texas, and is in charge of seismograph work being done by this company in West Texas.

JOSEPH A. SHARPE, Vice-President of Frost Geophysical Corporation of Tulsa, spoke in Midland March 31 at the invitation of the West Texas Geological Society on the topic "Aeromagnetometry—A Primary Reconnaissance Tool for West Texas."

RALPH E. MCMILLEN has been promoted to Chief Geophysicist for Phillips Oil Company in Venezuela and Colombia. Mr. McMillen is located in Caracas, Venezuela.

ELMER F. BLAKE has recently joined the supervisory staff of Southern Geophysical Company with offices in the Sinclair Building, Fort Worth, Dr. Sidon Harris, president of the company, has announced.

Mr. Blake will maintain his headquarters in the Fort Worth offices but will supervise several of the company crews operating in the Southwest and surrounding territories.

Having spent 13 years in the seismograph profession, Mr. Blake has been with Western Geophysical Company the past eight years. He comes to Fort Worth from Cheyenne, Wyoming, where he has been a party chief for Western in the Rocky Mountain area. He is a graduate of the North Texas State College in Denton.

FRANK ITTNER has been appointed Manager of Exploration for the Pacific Division of The Superior Oil Company. He will have charge of all geology, geophysical work, and land matters connected with exploration.

R. E. DAVIS of Southern Geophysical Company, Fort Worth, has been promoted from party chief to West Texas supervisor of the company, Dr. Sidon Harris, president, has announced.

Davis has been with Southern ever since the company was organized four years ago and previously was with Stanolind Oil & Gas Company for ten years. He is a member of the Society of Exploration Geophysicists and the Fort Worth Geophysical Society.

Now stationed in Tahoka, Texas, Davis will supervise several Southern crews now operating in West Texas.

MARION A. ARTHUR of the Humble Oil & Refining Company was elected President of the South Texas Section of the Society of Plastics Engineers for a term of office to run through 1949.

Dr. A. B. Bryan, chief geophysicist of the Carter Oil Company, will be transferred to the production research department of Standard Oil Development Company in New York on August 15, where he will work on the coordination of research activities in the field of oil finding and oil production. Dr. Bryan served as president of the Geophysical Society of Tulsa in 1948–1949.

Dr. Nelson C. Steenland, who recently completed his graduate work in geology and geophysics at Columbia University, has joined the staff of Gravity Meter Exploration Company, Houston, Texas. Dr. Steenland will be in charge of technical liaison between field operations, home office, and clients.

SPECIAL REGIONAL
MEETING NOTICE

REGIONAL EXPLORATION MEETING IN DALLAS

The Dallas Geophysical Society and the Fort Worth Geophysical Society will sponsor a regional exploration meeting at the Adolphus Hotel in Dallas, Texas, Thursday and Friday, November 17 and 18, 1949. Registration will commence the afternoon of November sixteenth.

The program subject has not yet been agreed upon, but papers, both geological and geophysical, of interest to exploration personnel in the Mid-Continent area will be presented. If possible, there will be a major subject interest directed to the continuation of both geological and geophysical considerations of reefs. It is planned to announce the titles of papers to be presented not later than September first.

A similar meeting in November of last year attracted nearly one thousand petroleum and mining scientists to Dallas from many parts of the Western Hemisphere.

O. C. Clifford, Jr., Atlantic Refining Company, is President of the Dallas Geophysical Society, and Dr. Sidon Harris, Southern Geophysical Company, is President of the Ft. Worth Geophysical Society. Both societies are local sections of the Society of Exploration Geophysicists.

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First Vice-President—E. M. McNatt, The Carter Oil Co., Box 801
Second Vice-President—N. J. Christie, United Geophysical Co., 822 Thompson Bldg.
Secretary-Treasurer—N. R. Sparks, Stanolind Oil & Gas Co., Box 591
Past President—A. B. Bryan, The Carter Oil Co., Box 801

Meetings on second Thursday, each month, October to May, inclusive, at 7:00 P.M. in Lorton Hall on University of Tulsa Campus. Visiting geophysicists are always welcome.

DALLAS GEOPHYSICAL SOCIETY

Regular Meetings
8:00 P.M.
2nd Mondays

President—O. C. Clifford, Jr., The Atlantic Refg. Co., Box 2819
First Vice-President—D. Ray Dobyns, Magnolia Petroleum Co., Box 900
Second Vice-President—H. C. McCarver, Seaboard Oil Co., 1400 Continental Bldg.
Secretary-Treasurer—T. R. Shugart, Geotechnical Corp., Box 7166
Past President—W. W. Newton, Geotechnical Corp., Box 7166

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First Vice-President—Derry H. Gardner, Humble Oil & Refg. Co., 258 Humble Bldg.
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Vice President Northern District: J. C. Waterman, Shell Oil Co., Inc., Bakersfield
Secretary-Treasurer: W. D. Cortright, Tide Water Assoc. Oil Co., Bakersfield

Informal Luncheon, Tuesdays, Bakersfield Inn, Bakersfield, and third Thursday each month Hotel Clark, Los Angeles. Annual Spring Meeting in Bakersfield. Annual Fall Meeting in Los Angeles.

FORT WORTH GEOPHYSICAL SOCIETY

President—Sidon Harris, Southern Geophysical Company
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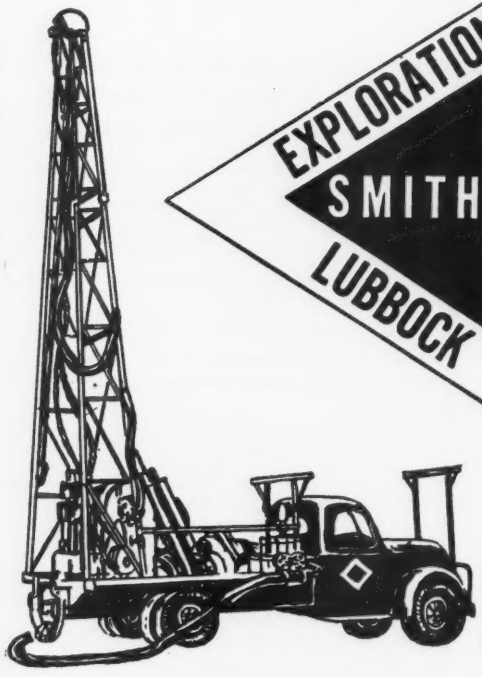

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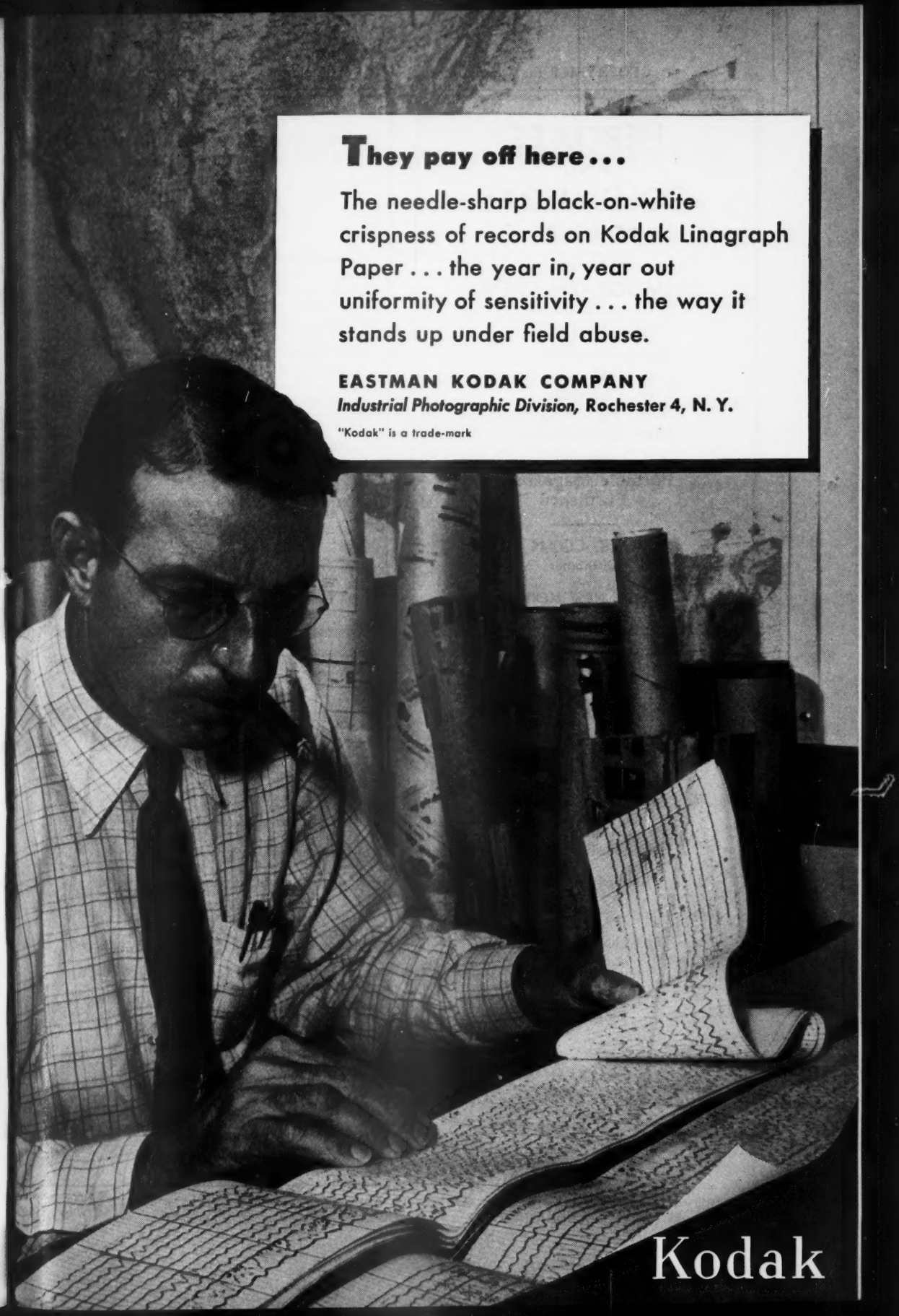
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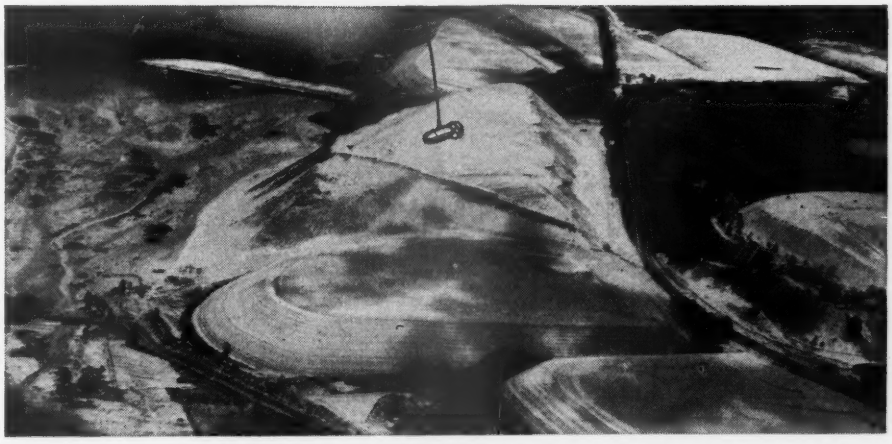

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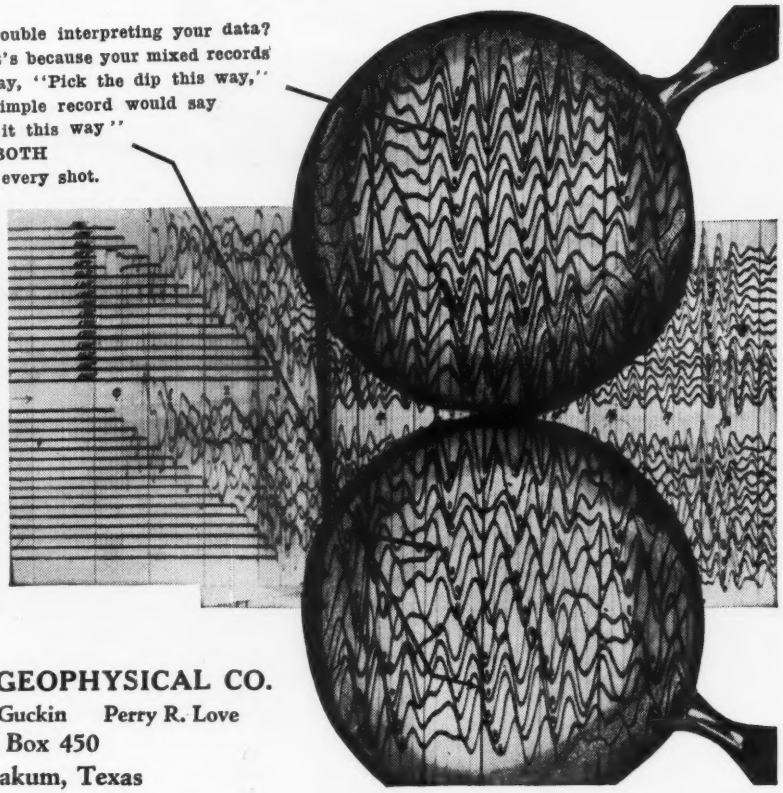

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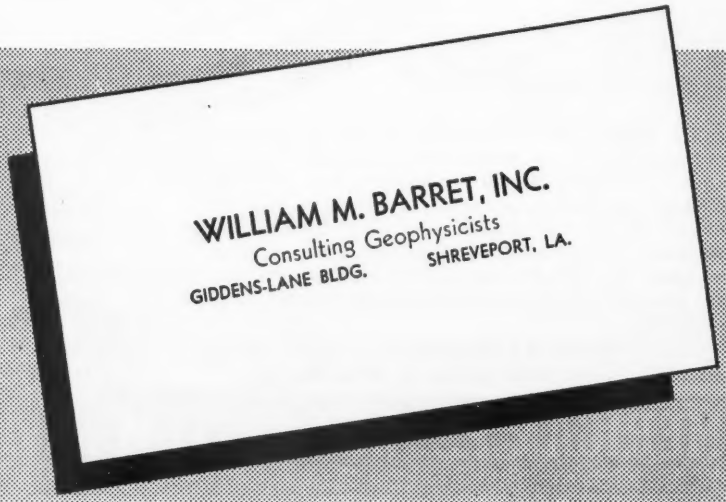

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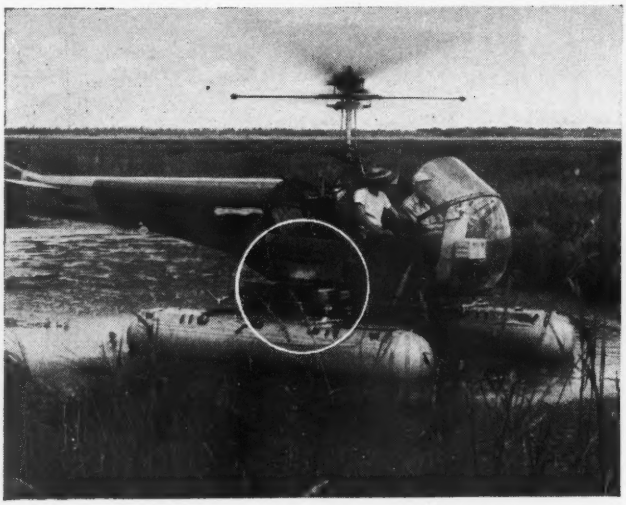

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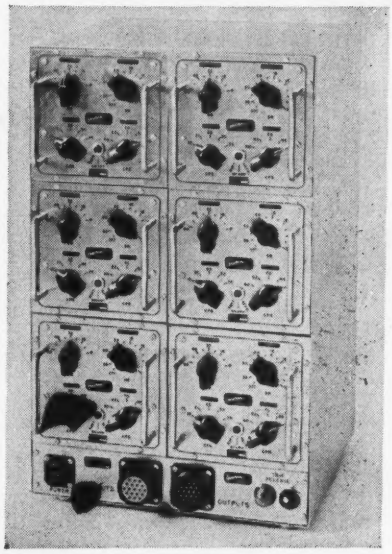

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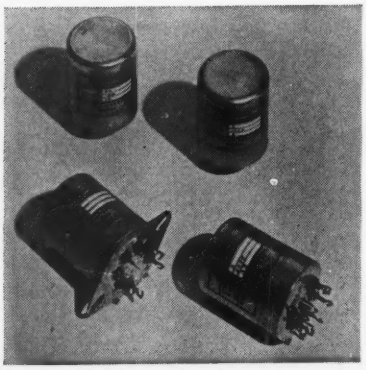

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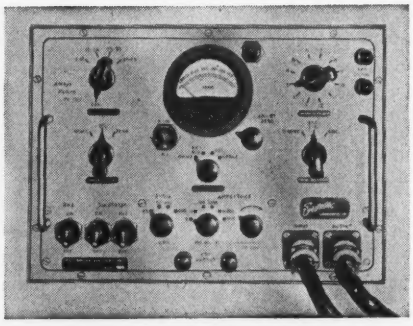

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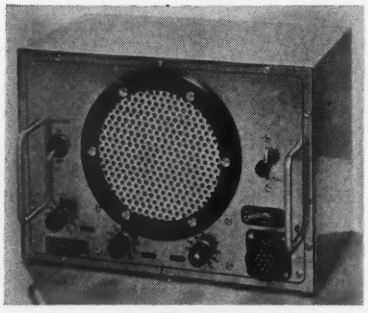

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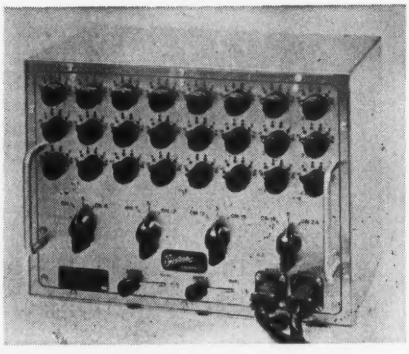

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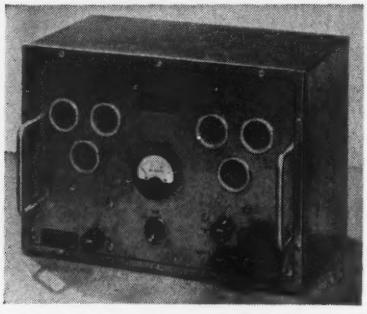

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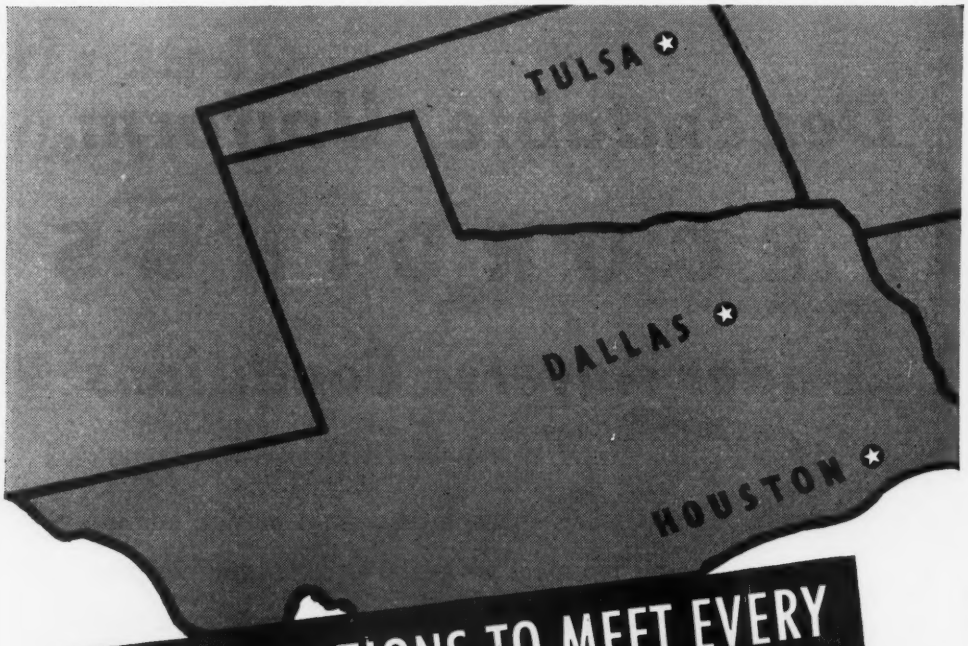

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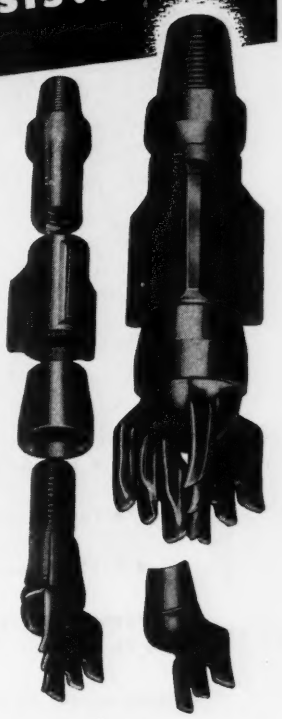

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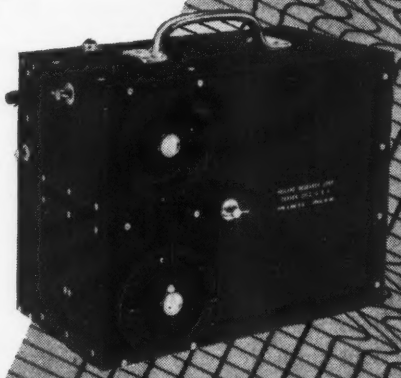

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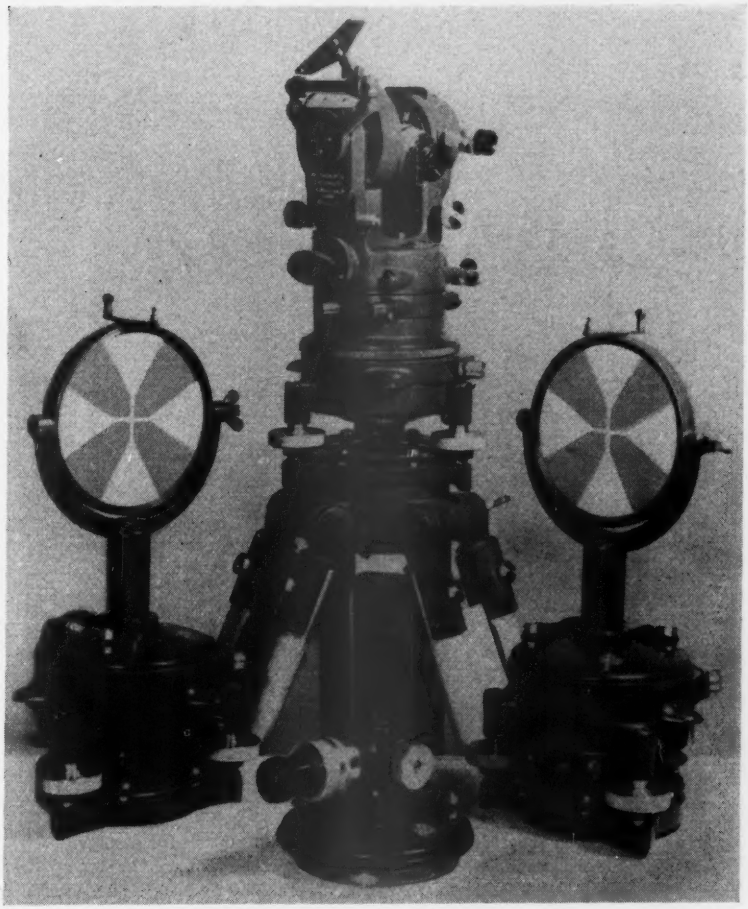

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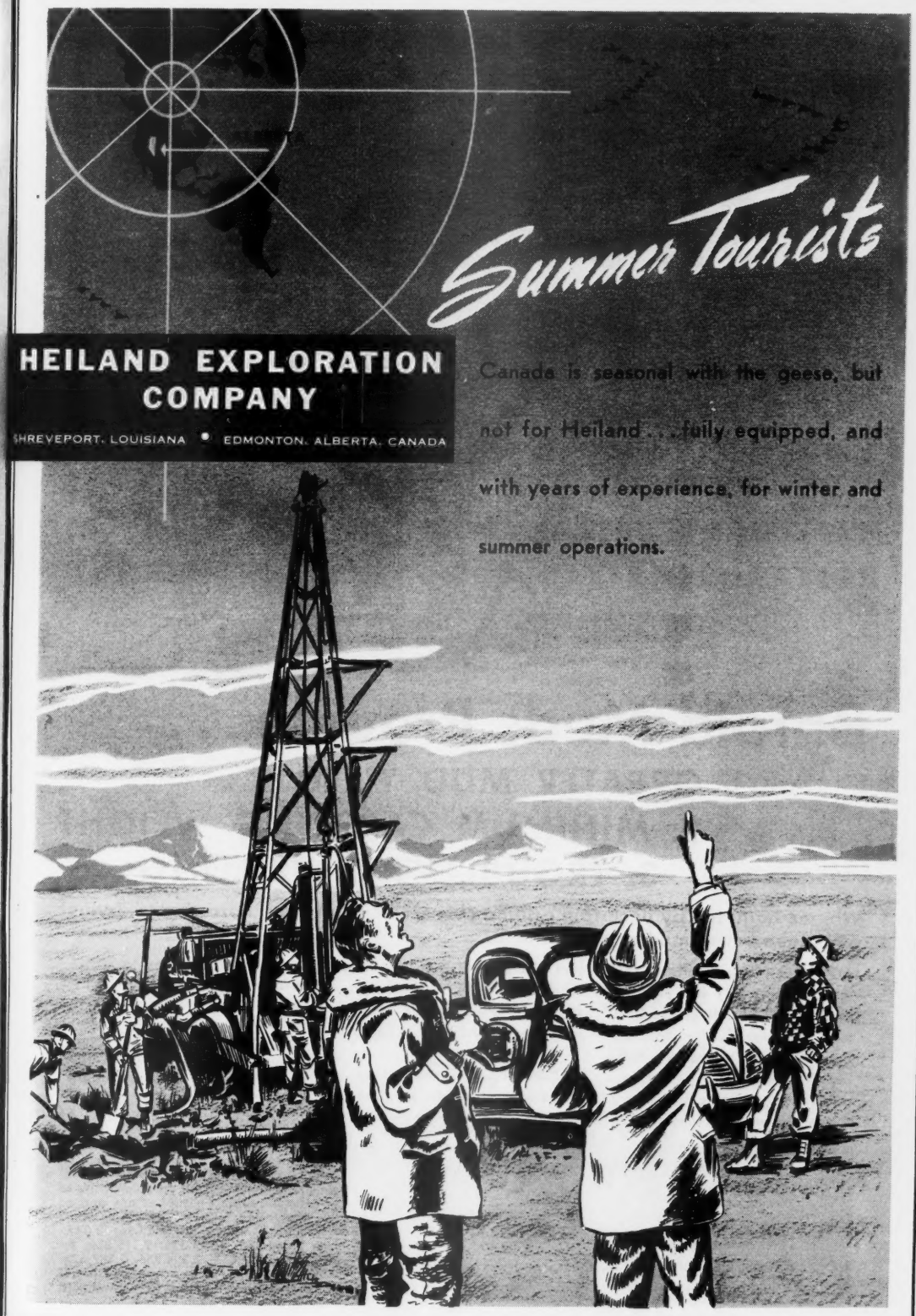

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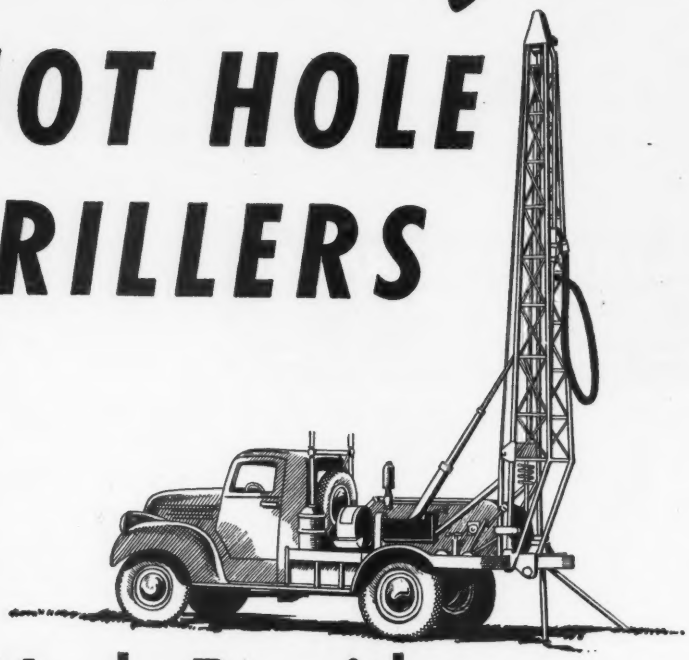

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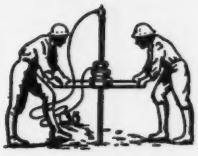

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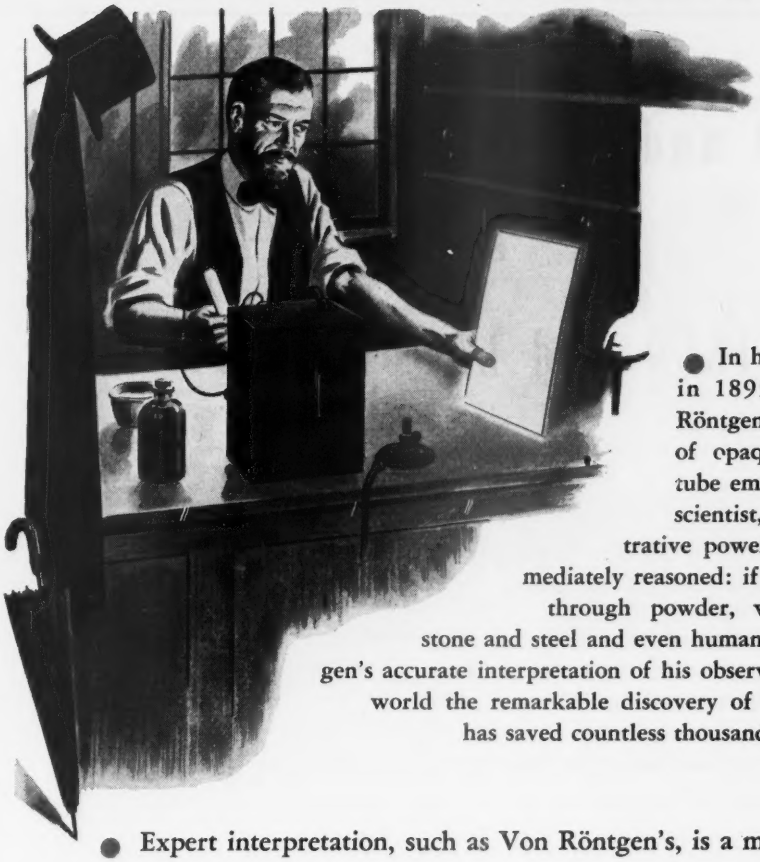

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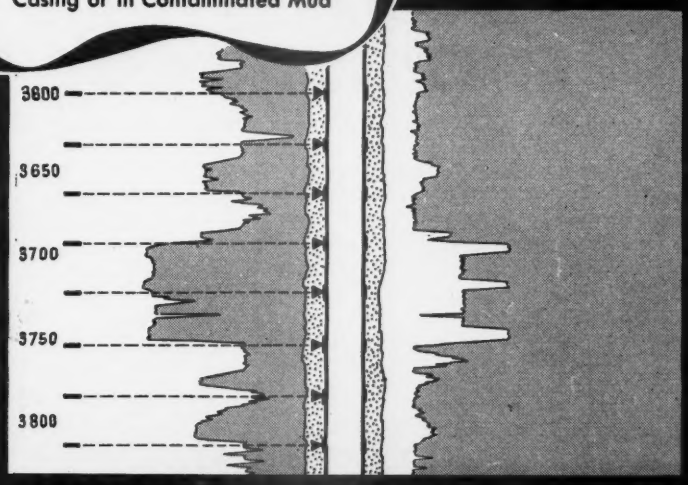

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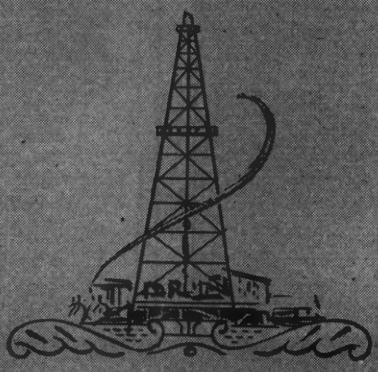

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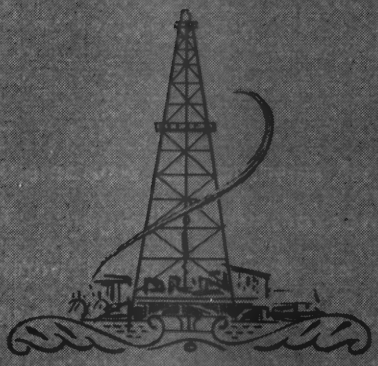

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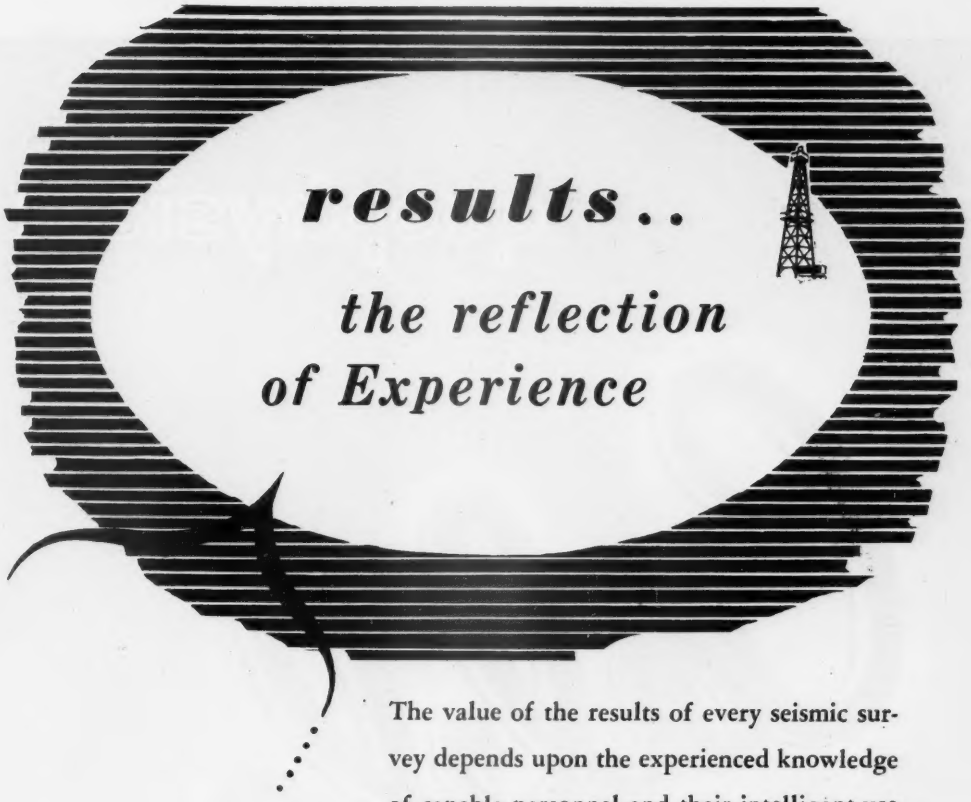

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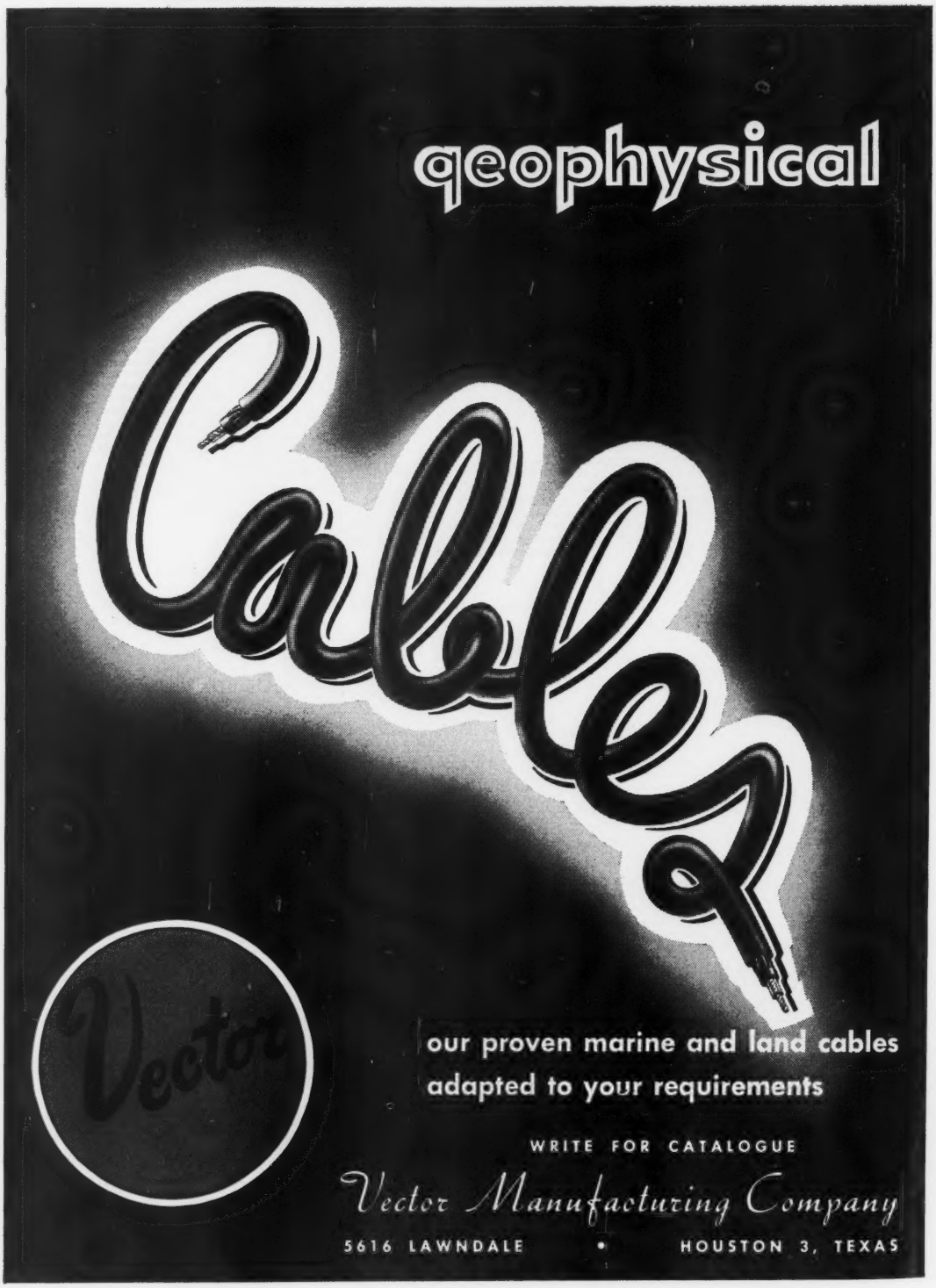
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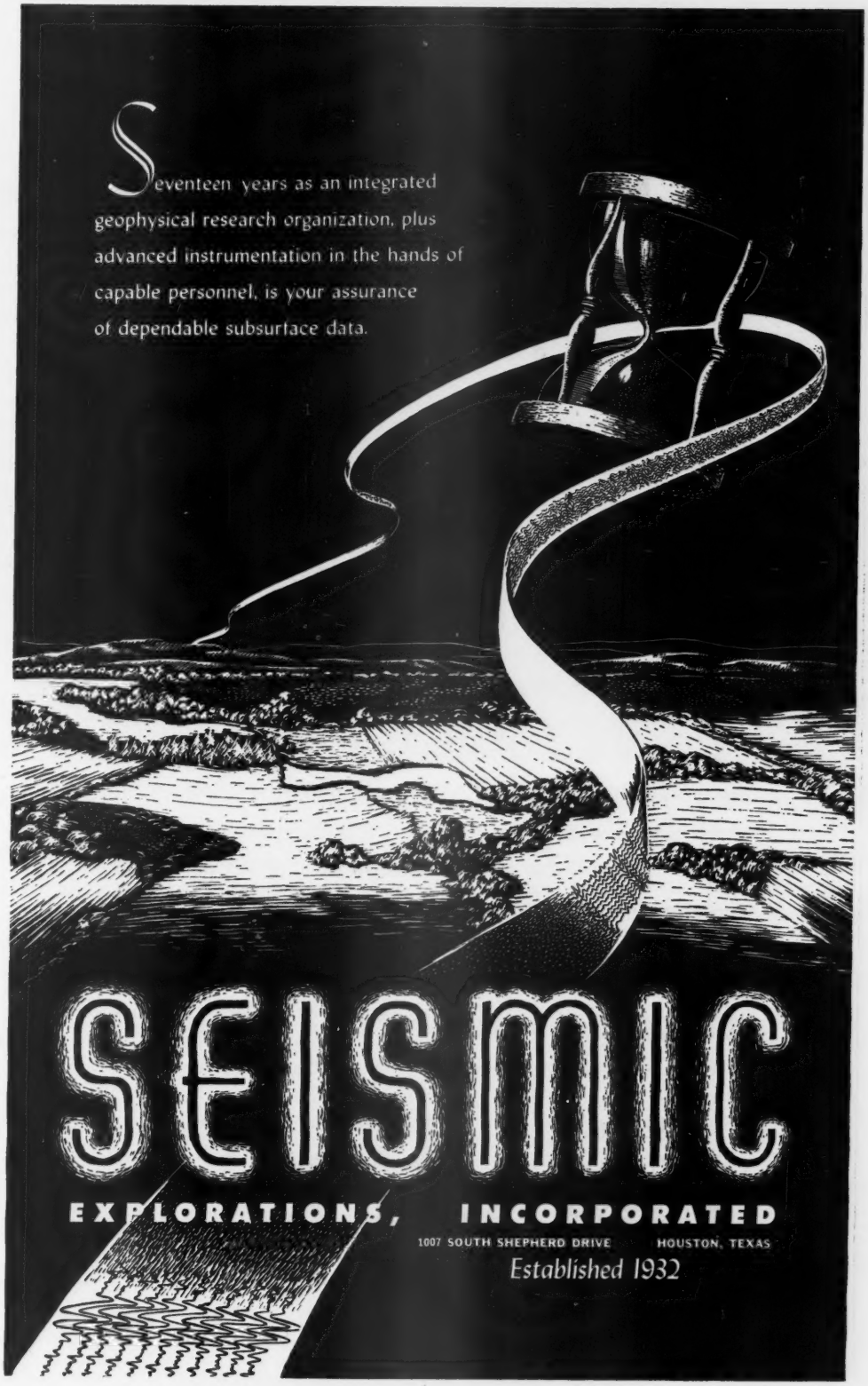
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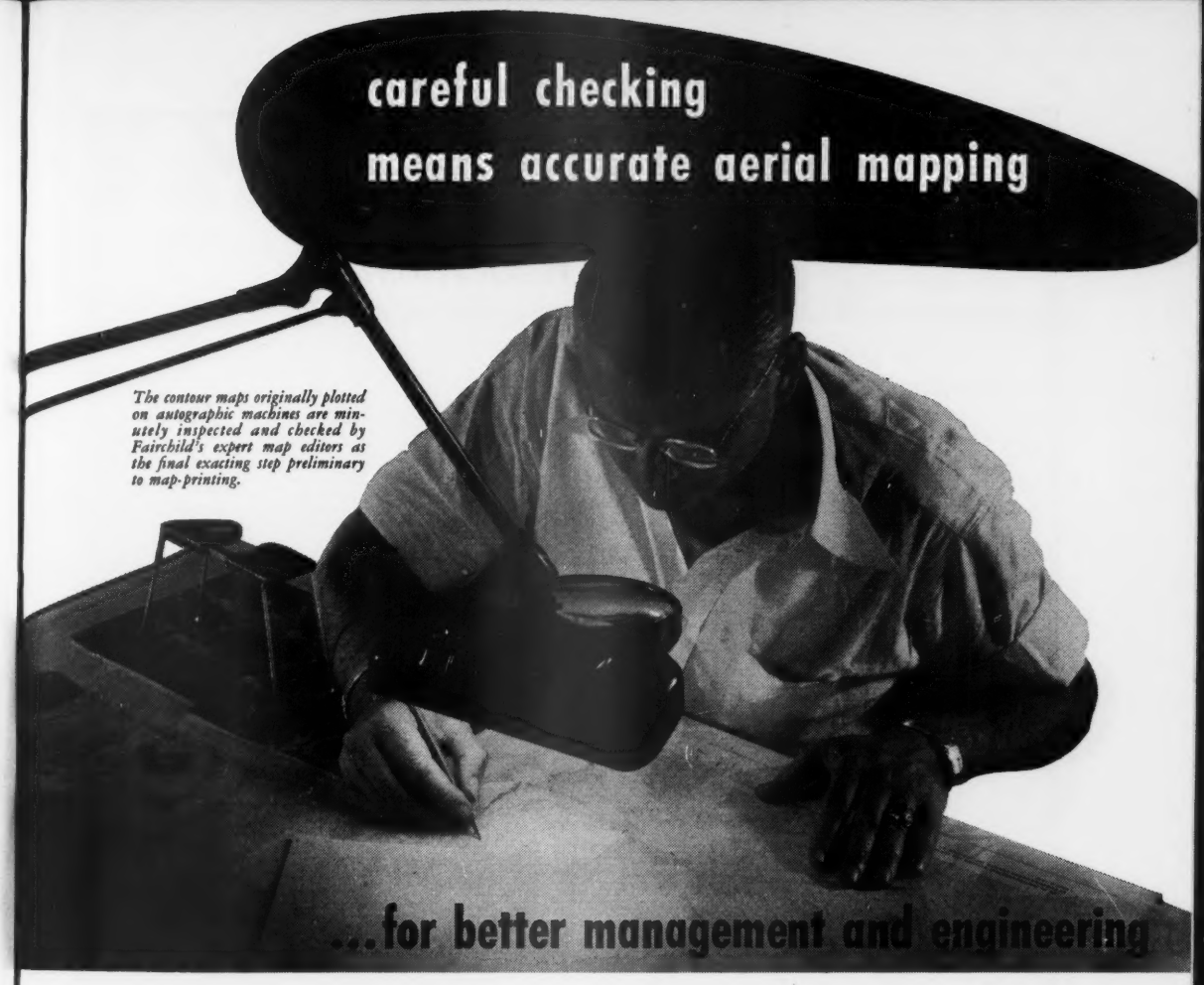
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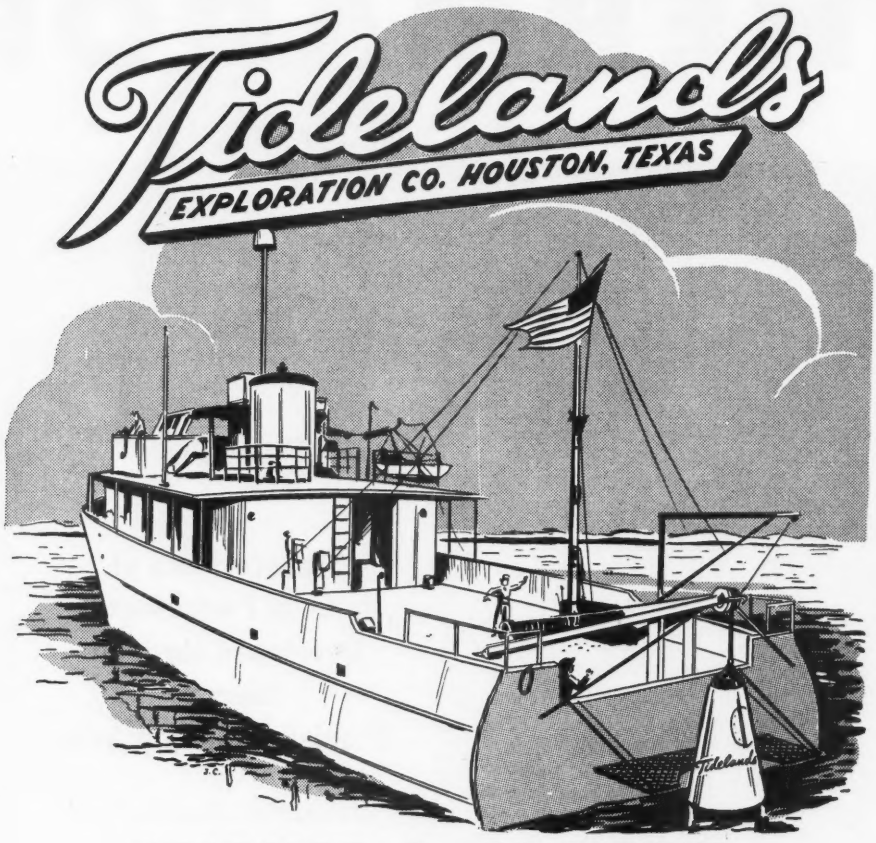

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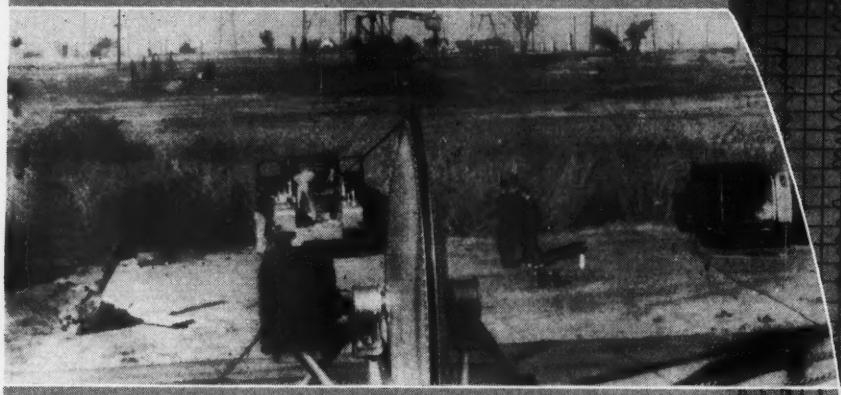

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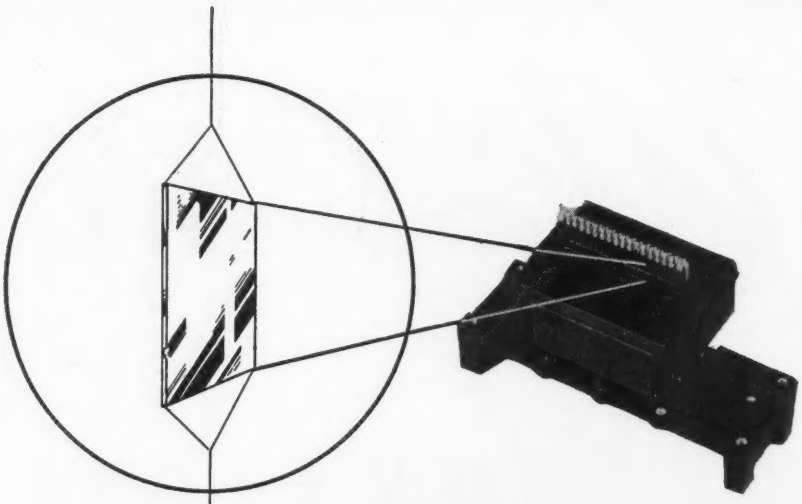

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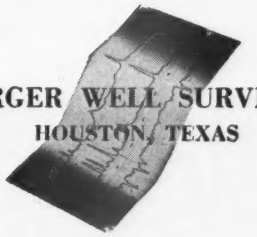

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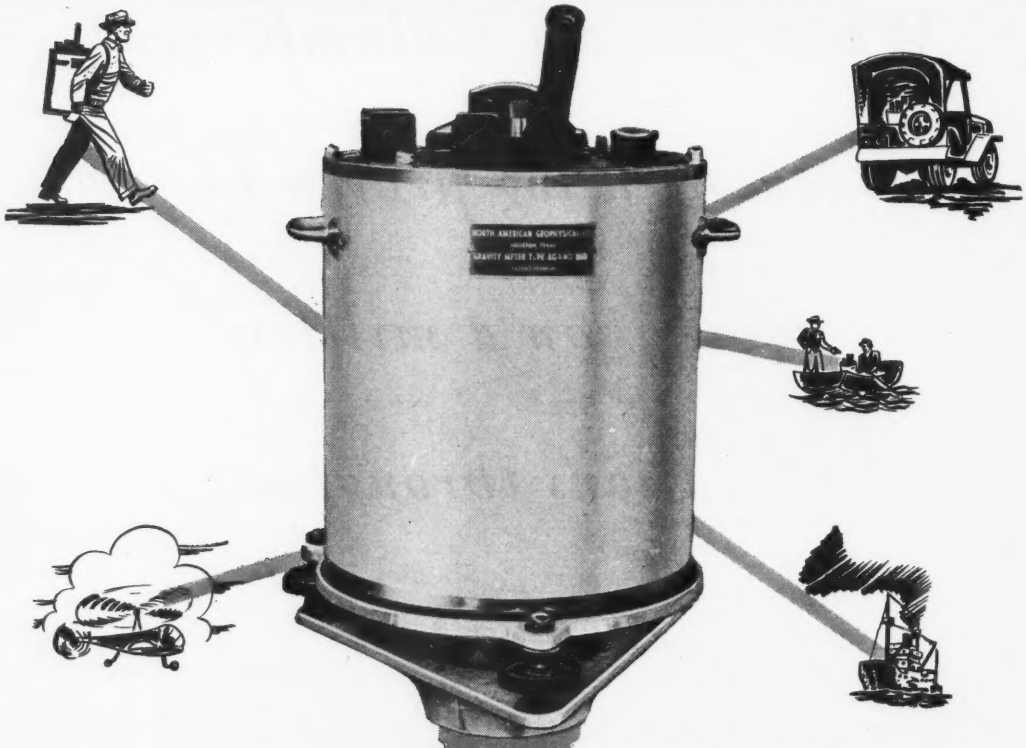

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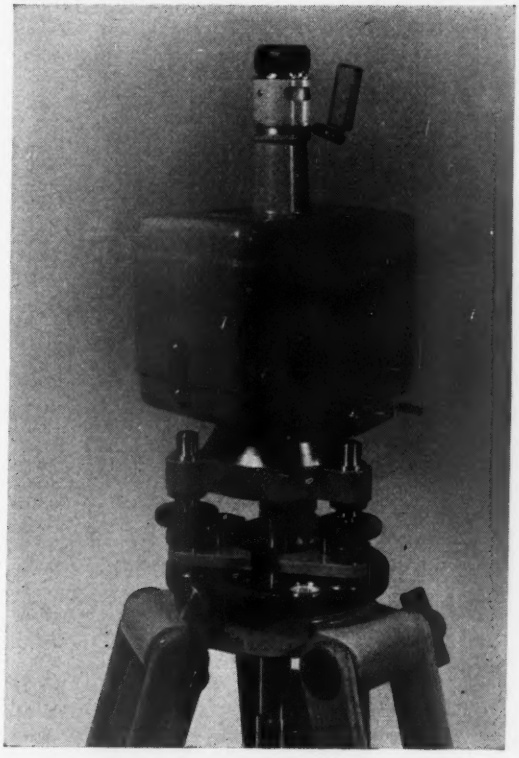

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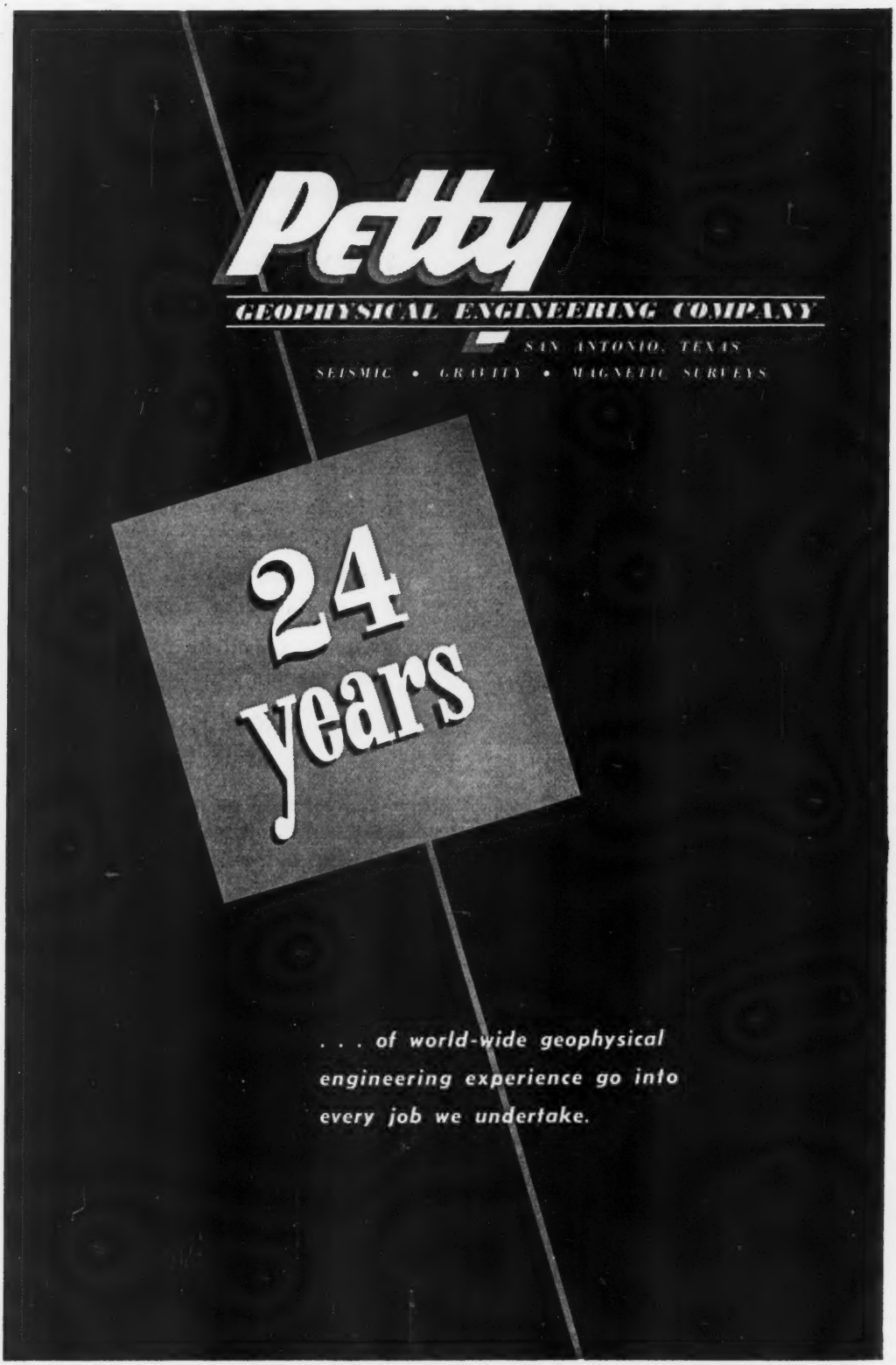
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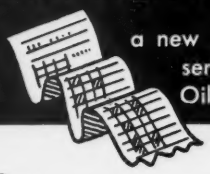

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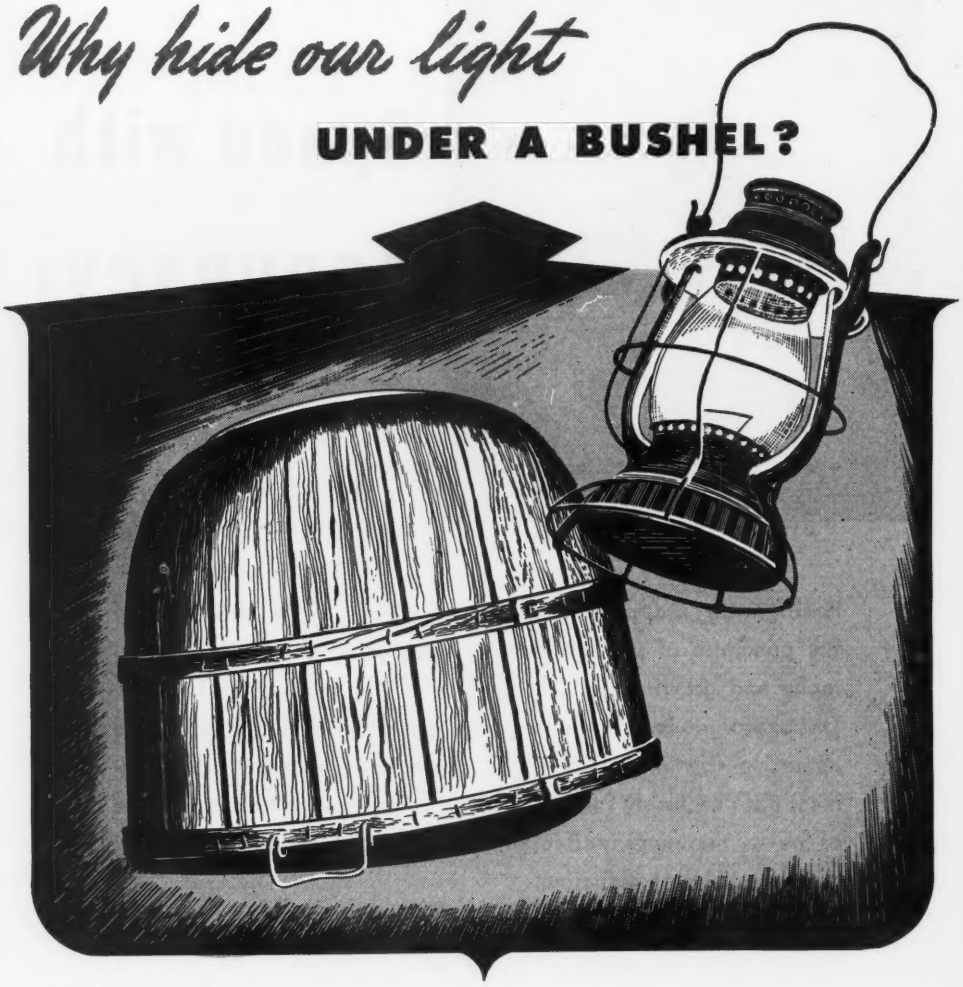

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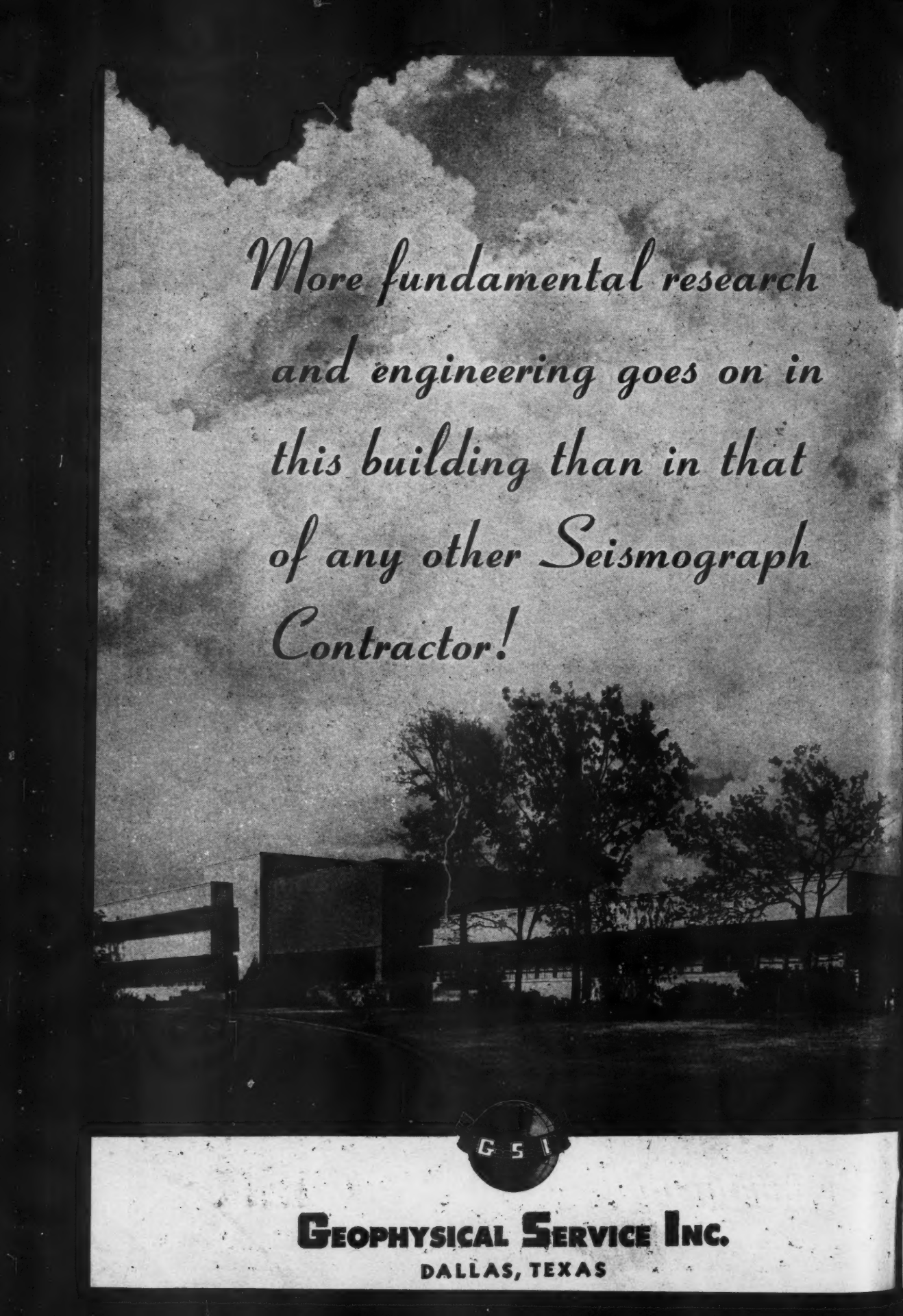
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